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CREW ESCAPE CONCEPTS FOR ADVANCED HIGH PERFORMANCE AIRCRAFT.(U)

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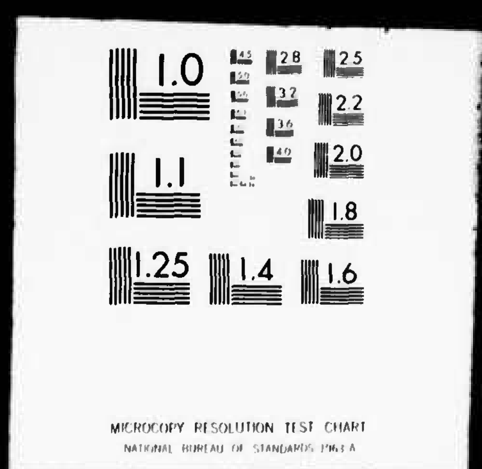

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CREW ESCAPE CONCEPTS FOR ADVANCED HIGH PERFORMANCE AIRCRAFT

BOEING AEROSPACE COMPANY
SEATTLE, WASHINGTON 98124

AUGUST 1978

TECHNICAL REPORT AFFDL-TR-78-56
Final Report for Period 1 September 1977 – 1 March 1978

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AIR FORCE FLIGHT DYNAMICS LABORATORY
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An investigation into the critical environments associated with escape from a high performance aircraft led to the evaluation of new crew escape concepts. Five of these concepts were compared in terms of their escape capability, cost, reliability, maintainability, development risk and impact on search and rescue operations. Following this comparison, three concepts were selected as having a potential for meeting all requirements. One concept utilizes a separable nose section for high speed or high altitude escape. Normal ejection occurs (over) over

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following deceleration or reduction in altitude. This concept is highly airplane configuration sensitive. The other two concepts are (1) an optional upward or downward ejection dependent upon the acceleration environment. The system is shielded by means of an extended wedge and stabilized by means of reaction jets; and (2) retained windshield/aftbody streamline. This system provides q protection through attachment of the windshield to the escape seat and a streamline aftbody for stability.

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FOREWORD

The research work in this report was performed by The Boeing Company, Seattle, Washington, for the Air Force Flight Dynamics Laboratory, Air Force Wright Aeronautical Laboratories, Air Force Systems Command, Wright-Patterson AFB, Ohio. The program was funded by the Laboratory Director's Fund under Contract F33615-77-C-2056, Project No. 2402, Task No. 240203. Project Engineer for the contract was Marvin C. Whitney, AFFDL/FER. This research work is part of an effort to obtain new crew escape concepts for providing safe survivable escape from high performance aircraft. The period covered is from 1 September 1977 to 1 March 1978 and the report was submitted on 9 March 1978.

Vinod K. Rajpaul served as the Program Manager. Douglas E. Swanson served as the Principal Investigator for the technical work. Other members of the Boeing Military Airplane Division assisting in the investigation included William Sander, Norman Gowin, Don Fisher, Christopher L. West, Leonard Witonsky, Teresa K. Laird, Sheri K. Bard, and Jeanne M. Owens. Henry Horn of the Boeing Wichita Division was consultant on the project providing a critical design review.

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LIST OF ABBREVIATIONS, ACRONYMS AND SYMBOLS

Alt	Altitude
ATS	A generic class of aircraft with a designated mission of air to surface weapons delivery
AFB	Air Force Base
BS	Buttock Station (aircraft coordinate system)
CACE	Cost Analysis Cost Estimate
C_o	Drag Coefficient
c.g.	Center of gravity
C_m	Pitching moment coefficient
c.p.	Center of pressure
F	Force
FY	Fiscal Year
flt	Flight
ft	Feet
g	Acceleration of gravity; units equal to the acceleration of gravity
G_X, G_Y, G_Z	Acceleration components along the x,y,z axes
I	Specific impulse (seconds)
in.	Inch
KEAS	Knots, equivalent air speed
ℓ	Hydraulic diameter, a reference length
lbs	Pounds
M	Mach number
M_m	Pitching moment
MMH/FH	Maintenance manhours/flight hour

LIST OF ABBREVIATIONS, ACRONYMS AND SYMBOLS (Cont'd)

N_2	Nitrogen
O_2	Oxygen
P	Pressure (static)
P_t	Pressure (total)
psf	Pounds per square foot
psi	Pounds per square inch
q	Dynamic pressure
R	Gas constant
^oR	Degrees Rankine
RAT	Ram air turbine
S	Projected frontal area
sec	Seconds
sta	Station (aircraft coordinate system)
t	Time
T	Temperature (static)
T_t	Temperature (total)
USAF	United States Air Force
V	Velocity
$\bar{V}$	Volume
W	Weight
$\dot{W}$	Weight flow rate
W. L.	Water line (aircraft coordinate system)
w.r.t.	With respect to
WSO	Weapons system officer
wt	Weight

LIST OF ABBREVIATIONS, ACRONYMS AND SYMBOLS (Cont'd)

γ	Ratio of the specific heats for a gas
Δ	The change in a quantity
ρ	Density
#	Number
%	Percent
ΔOEW	Change in operating equipment weight
ΔTOGW	Change in take off gross weight

SECTION I
SUMMARY & INTRODUCTION

SUMMARY

An investigation into the critical environments and problems associated with escape from a high performance aircraft led to some of the new concepts for crew escape from these aircraft. The concepts were screened and combined resulting in five concepts for comparison within a tradeoff study. The concepts were then configured within the framework of a combat aircraft with ATS mission. A tradeoff study compared each concept in terms of escape capability (Mach 3, 80,000 ft altitude, 2000 psf dynamic pressure, 6-10 g), airframe integration, cost, weight, reliability, maintainability, development risk and impact on rescue and survival operations. Three concepts show potential for providing escape from specified environment. These are the separable forebody, the optional ejection direction, and the retained windshield/aftbody streamline configurations.

The separable forebody utilizes a two phase escape sequence from high speed or high altitude situations. The first phase of the escape consists of separation of the nose section from the aircraft. Following deceleration and reduction in altitude the crewmember uses a current state-of-the-art ejection seat to escape from the forebody. This concept is highly dependent on airplane configuration.

The optional ejection direction utilizes an upward or downward ejection direction depending upon the magnitude of the acceleration forces. Stability for the system is augmented through use of a reaction jet control system mounted on a flow diverting wedge in front of the seat.

The retained windshield/streamline afterbody provides crew-member shielding by means of attaching the windshield to the ejection seat. Stabilization and reduction in wind drag deceleration forces is provided by means of a streamline afterbody.

The optional ejection direction and the retained windshield/streamline afterbody concepts are recommended for further in depth analysis, design and evaluation.

INTRODUCTION

High performance aircraft which may be operational in the 1985-1995 time period will operate within a more demanding environment than current aircraft. The escape system performance boundaries imposed by mach number, dynamic pressure and altitude are illustrated in Figure 1. The acceleration environment is bounded by 6-10 g along the $\pm G_z$ axis; 2-5 g along the $\pm G_x$ axis and 1-2 g along the $\pm G_y$ axis. These conditions and those encountered during an uncontrollable emergency far exceed the capabilities of current crew escape systems. Each of these environments lead to one or more specific problems associated primarily with that environment. Figure 2 provides a graphical illustration of the relationship between these new environments and severe potential problems. Thus high dynamic pressure leads to wind drag decelerations greater than human tolerance and also limb flailing type injuries. Each of the other environments, likewise, creates significant problems which may be fatal to the crew.

This study is directed toward the development and comparison of new crew escape concepts capable of saving crewmen's lives during escape from a damaged high performance aircraft designed for a basic ATS combat mission. In perfor-

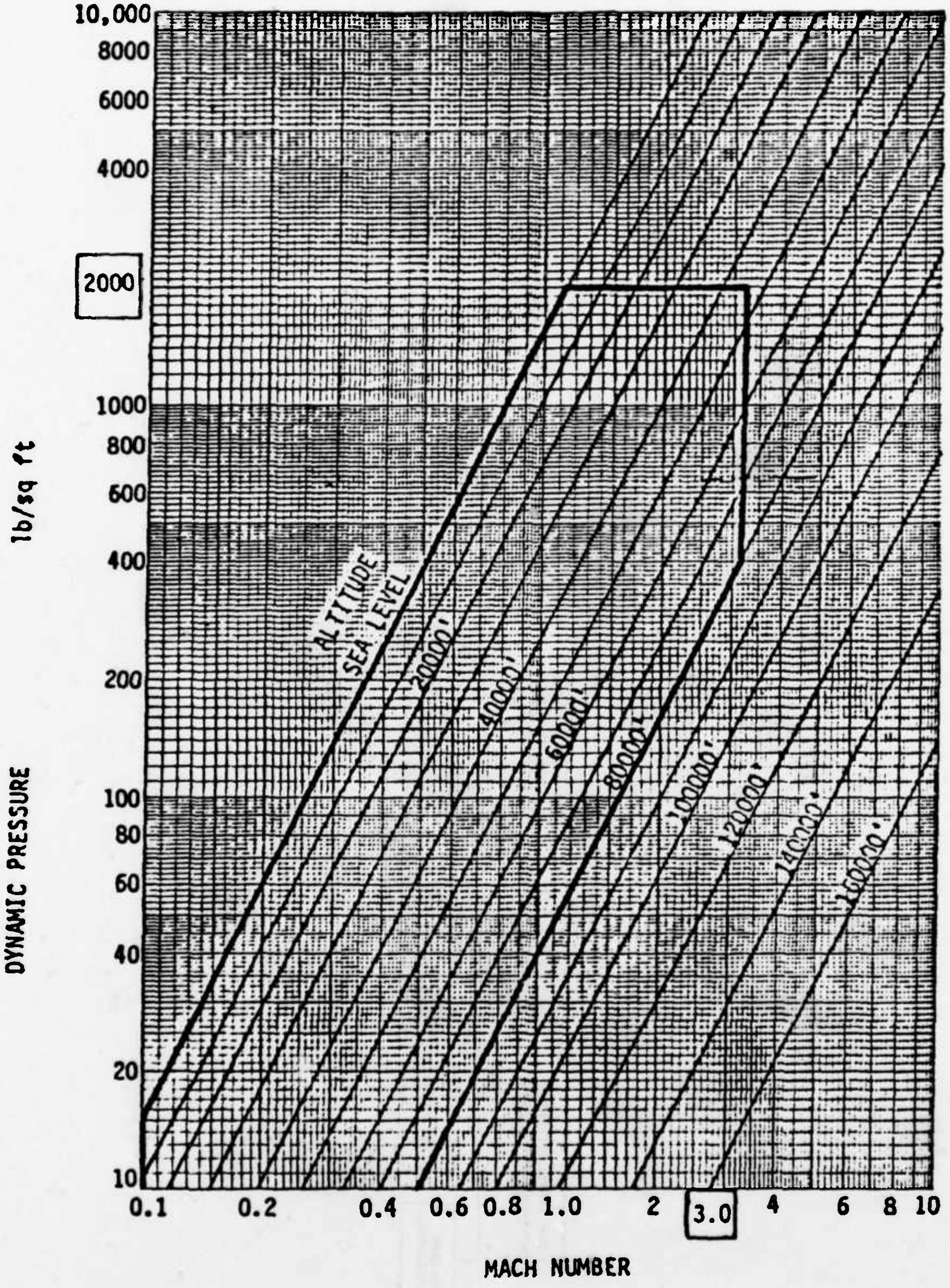


FIGURE 1 ESCAPE SYSTEM OPERATING LIMITS

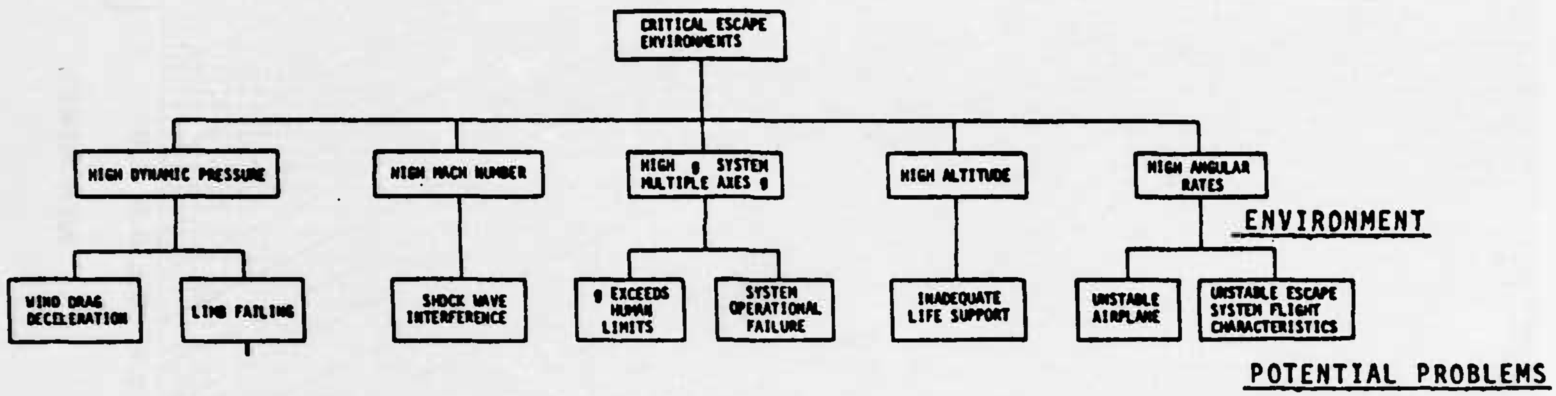


FIGURE 2 CREW ESCAPE ENVIRONMENTS AND THEIR POTENTIAL PROBLEMS

mance of this mission the aircraft is required to fly under new and extreme limits of altitude, acceleration, dynamic pressure, mach number, and excursions in angular rates. The escape system is required to perform following an uncontrolled emergency during any portion of the combat or non combat mission without resulting in serious injury to the crew, and with a high success rate.

While escape systems are provided for crew survival after their aircraft is fatally damaged by enemy action, the system is carried and needed during non-combat missions also. The combat record of existing systems is much better than the non combat record, probably because severe damage by enemy action is relatively easy to assess, and there rarely is an accident investigation after crew bailout in the combat situation. During the non combat mission there is a tendency for the crew to delay their escape attempt until the choice is obviously between sure death in the crash and use of the escape system.

In view of the above it appears that a good escape system must have at least these attributes:

1. Rugged enough to withstand many years of use in the combat and the non combat environment.
2. Simple enough so that the user can understand the function and can verify system status by personal inspection.
3. Fast acting so as to be forgiving of any procrastination practiced by the crews.
4. Low life cycle cost so that the cost of acquisition and maintenance does not exceed the utility of the system.

5. Positive control so that the aircrew is never in an uncontrolled situation throughout the escape sequence.
6. Safe in that it provides assurance of return to the home base by all of the crew without physical injury.

The method utilized in conducting this study provides an evaluation of each problem in its fundamental terms and of developing concepts of mechanization which offer a potential solution. These potential solutions are screened, combined and refined to provide a set of selected concepts for comparison within the trade off studies. The trade off studies incorporate factors such as the escape capability, airframe integration, cost, weight, reliability, maintainability, development risk and impact on rescue and survival operations.

The baseline aircraft chosen for escape system integration is the Boeing Model 987-230B ATS aircraft. The aircraft is a two place trainer version of the combat aircraft. The forward pilot has a fixed seat back angle of 50° whereas the aft pilot position has a seat back angle of 35°, hence it also provides a good basis for evaluating the effect of different seat back angles on the escape concept. The general arrangement for this model is shown in Figure 3.

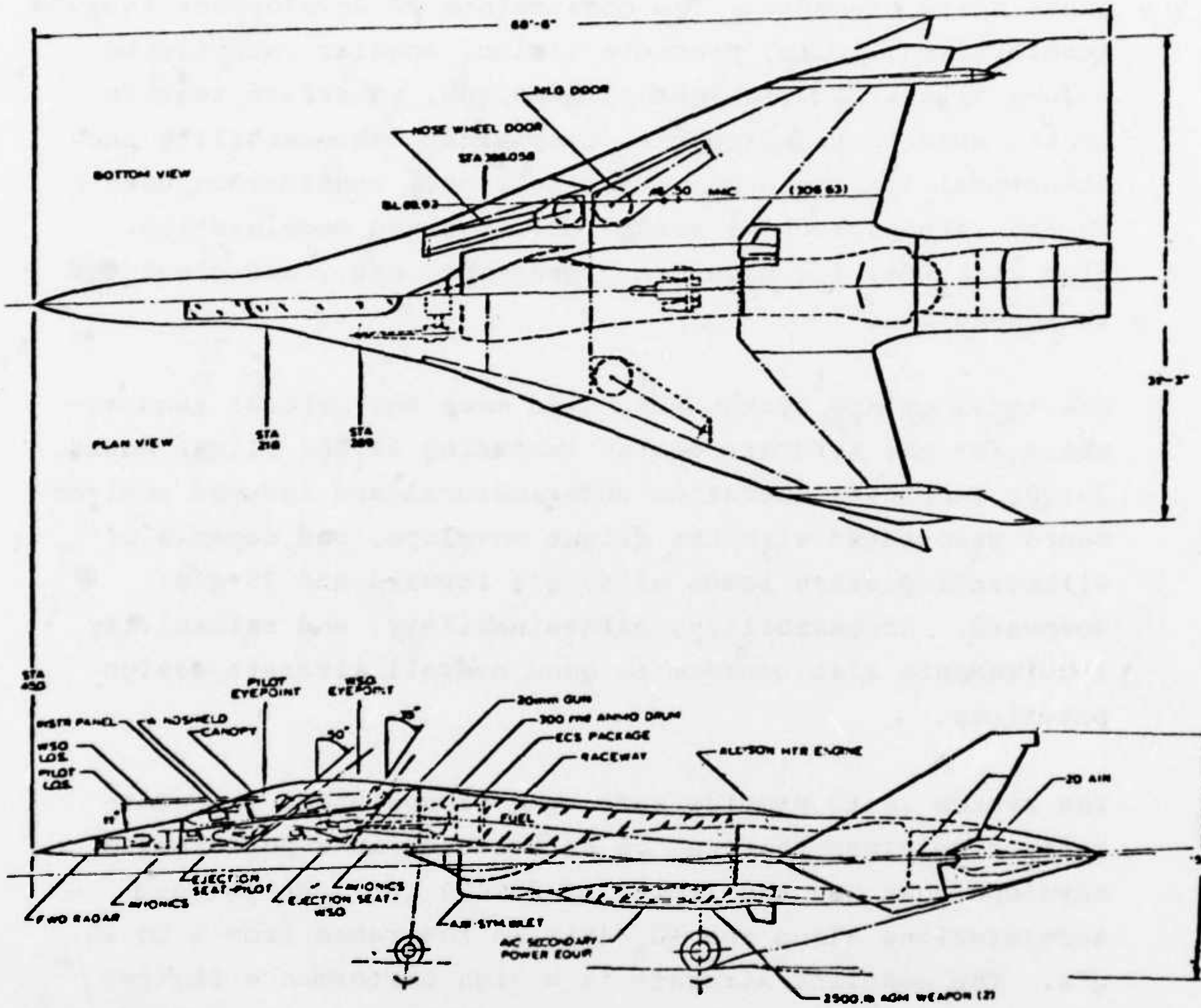


FIGURE 3 GENERAL ARRANGEMENT OF MODEL 987-230B ATS AIRCRAFT

SECTION II
REQUIREMENTS & BASELINE DATA

The performance requirements for the escape system are based upon physical limitations of the man, the escape system, the aircraft and the interrelationships between these basic elements. The constraints of development include acceleration limits, pressure limits, angular rate limits, volume allocations, weight allocations, interface requirements, mission requirements, complexity, accessibility and structural limitations. Human tolerance constraints used in this study, such as abrupt or sustained deceleration, high altitude, low pressure protection, etc., are presented in Appendix A.

The total escape system must also meet the general requirements for the aircraft design including 20,000 flight hours, 30,000 landings, operation under natural and induced environments associated with the flight envelope, and capable of withstanding crash loads of 40 g's forward and 25 g's downward. Accessibility, maintainability, and reliability requirements also conform to good overall aircraft design practices.

The system is to provide safe crew escape under the emergency conditions that can be encountered in a performance envelope that has the limits of 80,000 ft, 2000 psf and accelerations along the $\pm G_z$ axis in the range from 6 to 10 g's. The baseline aircraft is a high performance fighter type aircraft which has a primary mission of air-to-surface weapons delivery. This aircraft incorporates a two-man tandem seating arrangement thus addressing the difficult problem of providing safe escape for two crewmembers. In

addition, an effective escape capability for low altitude and adverse attitude conditions is essential.

The problems associated with aircraft integration consider low profile cockpits, semi-supine position with back angles up to 50°, side arm flight control, single piece windshields and canopy design for increased external vision. Also the problems associated with multiple axis acceleration generated by control configurations which permit direct lift, direct side force and drag modulation are investigated.

The overall capability of each concept is investigated to minimize weight penalty upon the aircraft. High reliability and a minimum of maintenance are a goal. Costs associated with development, acquisition and service support for the proposed designs are also considered. The data for development of cost, weight and maintenance manhour requirements on current systems is obtained from USAF operational experience data banks.

SECTION III
METHOD OF EVALUATION

A means of comparing the overall desirability of each concept was formulated. The primary objective for development of this method was to provide a tool for selecting the best concept(s) from the five candidate concepts. A secondary objective was to provide a versatile method which would allow comparison of the candidate concepts with concepts not selected in this study. Although the method may be limited by the level of detail upon which predictions are based, it should provide a means for refining comparisons as the level of detail in the analysis increases.

The method utilized is composed of three separate steps. First the performance of each concept is predicted in terms of basic evaluation items. Second, the predicted performance is rated in terms of the requirements within each category. Finally, the overall design desirability is obtained through incorporation of the relative importance of each evaluation item with respect to each other evaluation item.

Several methods exist for predicting performance in terms of the evaluating items. The choice of prediction scheme is usually dependent upon the level of detail by which the concept is defined and also the availability of data concerning the evaluation item. Some of these methods are: persistence prediction, associative prediction, analog prediction and intuitive prediction. Persistence prediction simply assumes that conditions will be the same in the future as they were in the past. Thus, applying current technology components will result in the same reliability of that component as it did in the past. Associative prediction utilizes causality. Thus, increasing the total

number of components causes the overall system reliability to decrease. Analog prediction is based upon scientific laws and mathematical models. Thus, performance can be estimated from basic laws of physics and based upon appropriate computer simulations. Intuitive prediction is based upon overall experience and intuitive judgement.

Rating the predicted performance for each concept in terms of the evaluation items is accomplished through attaching a value to the desirability of the predicted performance. This is very difficult to do quantitatively in a wholly satisfactory way. Value is an elusive quantity to measure. The value, or utility, of predicted performance is therefore often intuitively determined based upon the optimum desired performance within each evaluation category. The method utilized within this study rates the utility of the predicted performance from 0.0 to 1.0 based upon the requirements stated in Section II. For example, the escape system is required to perform up to a dynamic pressure of 2000 psf. A rating or utility function for this evaluation category is determined on the basis of what percent of the total performance envelope the concept is capable of covering.

In general, the value of a particular evaluation item is a function of many items at once and not necessarily a simple linear combination. However, it is very difficult to measure the overall contribution of all variables. Therefore, in quantitative terms we treat each evaluation category separately and ignore interactions. Thus, in determining the utility function for weight we are concerned with the inherent desirability of the weight or change in weight and are not concerned that lowering weight may increase costs. The value of each of the candidate concepts is determined in terms of the following eight

categories:

- o Emergency escape capability
- o Aircraft integration
- o Life cycle cost
- o Development risk
- o Impact on normal crew functions
- o Reliability
- o Maintainability
- o Impact on survival and rescue operations

Each category is assigned a relative importance for use as a criteria in selecting the final concept. The final decision for selecting the best concept(s) is obtained by selecting those concept(s) with the highest value.

EMERGENCY ESCAPE CAPABILITY

The emergency escape capability is divided into six sub categories or evaluation items. These evaluation items consider escape system performance within the following environments:

- o High g's
- o High altitude
- o High dynamic pressure
- o High mach number
- o Unstable flight conditions
- o Low altitude/adverse attitude

The prediction of escape system performance under high g's is based upon an estimated g during which escape may be initiated. For this study the prediction is obtained from a three degree of freedom simulation of the initial ejection phase for each of the proposed concepts. The value of this predicted performance is rated as a percentage of the total performance envelope under which the concept is capable of covering as shown in Figure 4a.

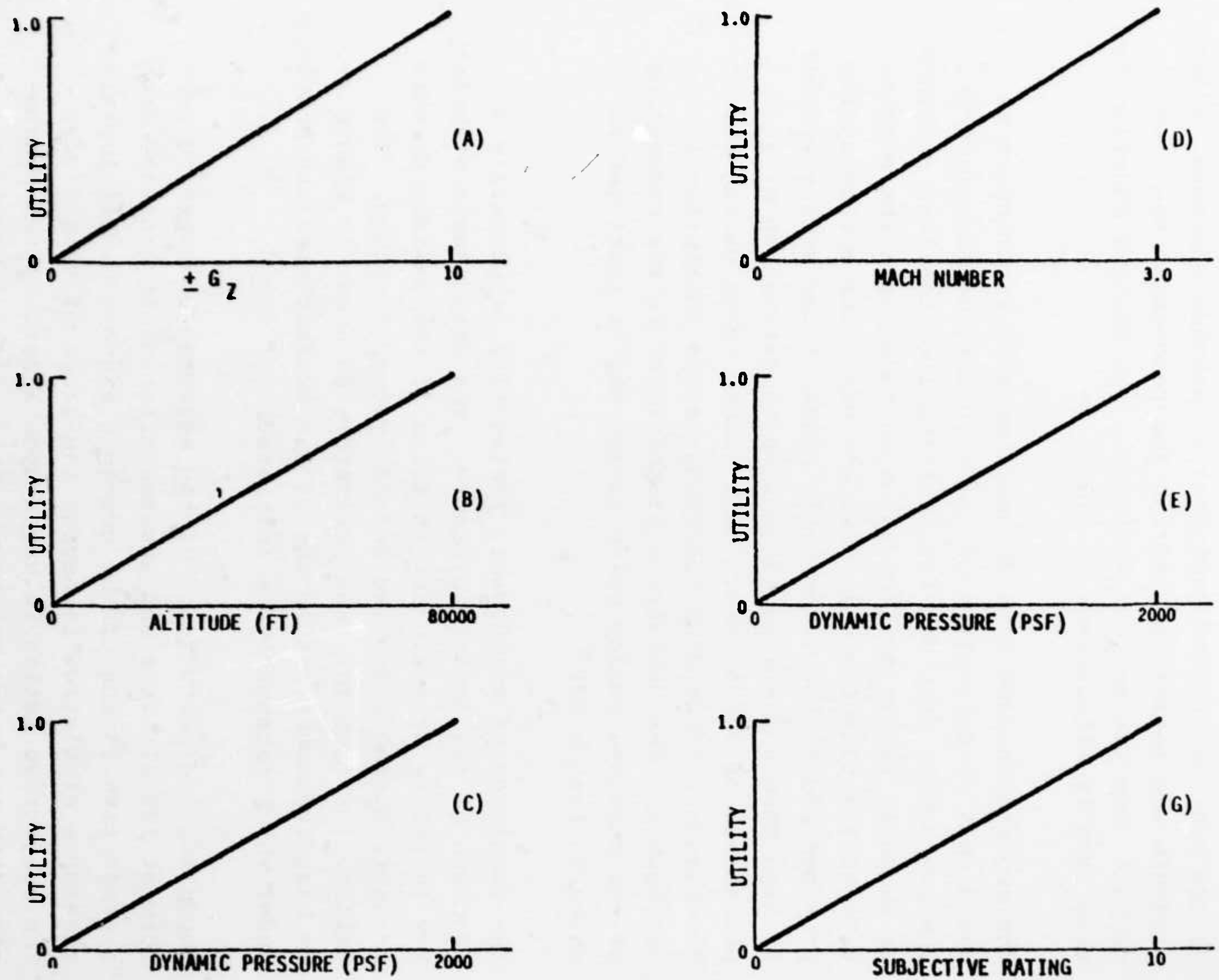


FIGURE 4 EVALUATION OF UTILITY FUNCTION

(A) High Maneuver Acceleration, (B) Altitude, (C) High Dynamic Pressure, (D) Mach,
(E) Aerodynamic Stability, (F) Low Altitude/Adverse Attitude

The high altitude capability of each concept is predicted by the availability of equipment to provide adequate oxygen, pressure and thermal protection for recovering the crew-members from the maximum altitude. The utility function for this item is illustrated in Figure 4b.

The protection from high dynamic pressure environment is based upon an estimation of the wind drag deceleration and the protection provided for limiting limb flailing problems. As shown in Figure 4c, the value is based upon the percentage of the flight envelope within which the escape system provides protection. The performance of the escape systems at high mach numbers is based upon an estimation of the percentage of the aircraft mach number range during which shock wave interference following escape initiation is negligible. The utility is proportional to the percentage of the envelope during which escape may be initiated as shown in Figure 4d.

The magnitude of aerodynamic instability is primarily a function of the dynamic pressure. The aerodynamic stability may therefore be evaluated in terms of the maximum dynamic pressure during which the escape system is stable. The utility function for this parameter, as shown in Figure 4e, is based upon the percentage of the dynamic pressure envelope under which escape may be initiated.

The predicted performance of the selected concepts to perform at low altitude and adverse attitude is obtained from a subjective rating of the concepts since a detail terrain clearance simulation is beyond the scope of this study. The subjective rating is based upon a zero to ten evaluation with ten being the best. This rating takes into account the ability of the system to provide equivalent

escape capability with current escape systems, including the case where the aircraft is inverted. The utility function shown in Figure 4f illustrates the direct proportioning between the rating system and the utility.

AIRFRAME INTEGRATION

The airframe integration category consists of three evaluation items. These three items are:

- o weight penalty
- o volume penalty
- o integration complexity

The weight penalty is based upon a detail weight analysis of the escape system, cockpit, supporting equipment and related aircraft structural additions or deletions. Since some of the proposed concepts utilize structural portions of the aircraft, the weight analysis considered the change in weight of the entire fuselage section surrounding the cockpit area for determination of the overall weight penalty. The actual weight penalty incurred as a result of incorporating an escape system could be substantially more than just the escape system hardware because of the interrelation of airplane structural requirements and airplane mission or range degradation. As an example, it would be expected that a relatively heavy escape system would cause some degradation in range performance. If this range degradation is unacceptable, then additional fuel will be required. Carrying more fuel will necessitate larger fuel tanks, hence more structure and larger landing gear, increased thrust to meet takeoff requirements, etc. and consequently, increased costs. Typically for an ATS mission airplane the ΔOEW:ΔTOGW ratio is 1:2. The estimated escape system weights provide a guide in estimating the total weight penalty including effect on aircraft performance and structure. The utility function for this item is determined after the

weight is estimated for all concepts. The minimum weight configuration is used for comparison with all other proposed concepts receiving a utility from 0 to 1.0 based upon the ratio of the minimum weight escape system weight to the proposed escape system weight as shown in Figure 5a.

Prediction of the volume penalty is based upon the estimation of the total aircraft volume dedicated to the escape system concepts as shown in their respective configuration drawing layouts. This dedicated volume includes both the volume for escape system components and subsystems as well as the volume of aircraft space which must be clear through which to eject. The utility function is based upon the comparison of each system with the minimum dedicated volume system as shown in Figure 5b.

Prediction of the overall system integration complexity is based upon the number of interfaces between the escape system and the aircraft, more interfaces means a more complex integration. The number of interfaces is determined through the concept component lists and their respective configuration drawings. The utility function is determined following analysis of all concepts and determining the concept with the least number of interfaces. The utility function is then determined as shown in Figure 5c through the ratio of the concept with the minimum number of interfaces to the number of interfaces for the other concepts.

LIFE CYCLE COST

The life cycle cost evaluation includes development (RDT&E), acquisition, operations and support costs. The estimates were calculated in terms of FY1977 dollars considering a 15 year operating period.

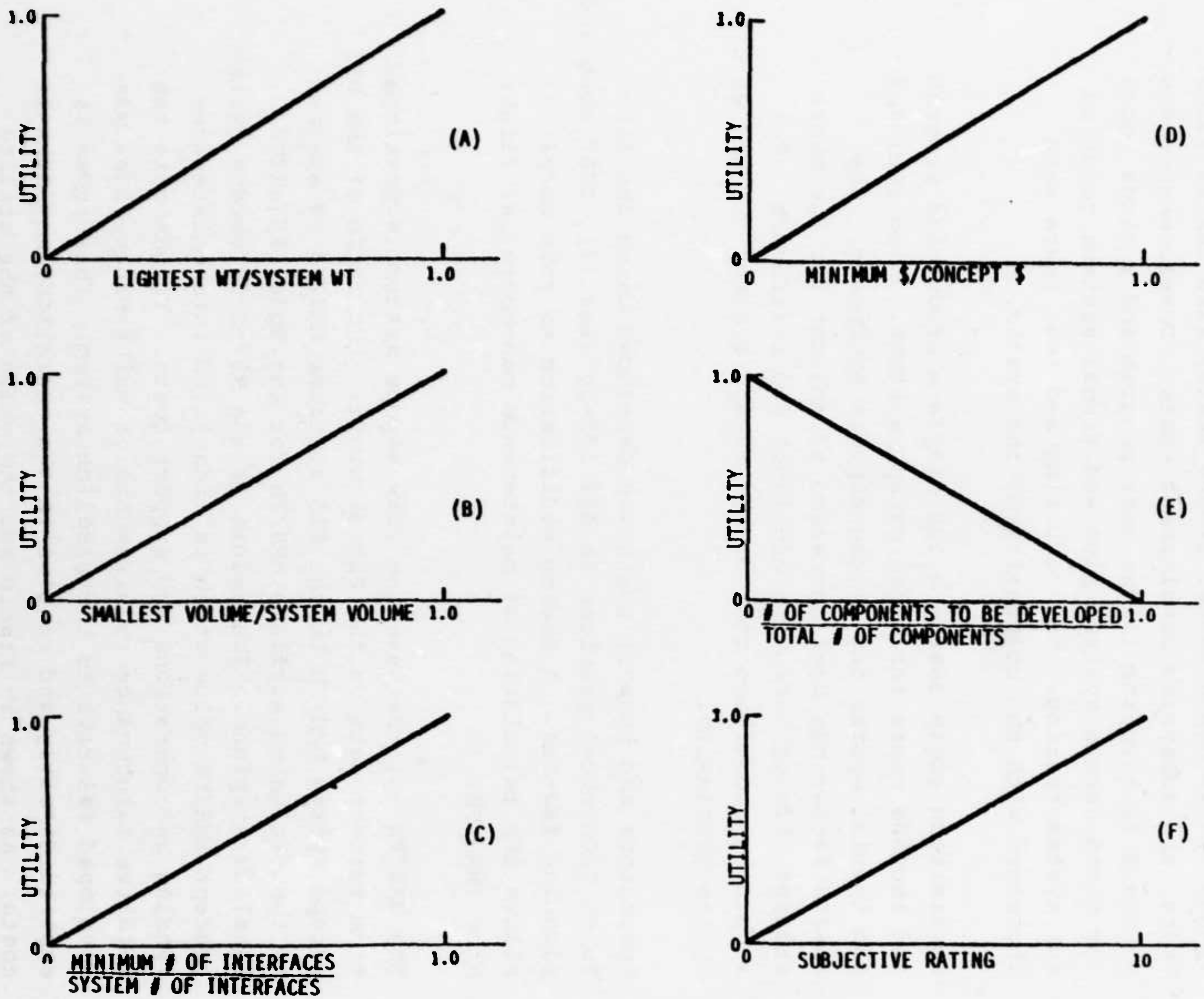


FIGURE 5 EVALUATION OF UTILITY FUNCTION

(A) Weight Penalty, (B) Dedicated Volume Penalty, (C) Integrated, (D) Life Cycle Cost, (E) Component Development Risk, (F) Overall Development Risk

Development costs include computer simulation, wind tunnel tests, static bench tests, ground tests, sled tests, flight tests, and subsystem development costs. Development costs assume a 20 airplane flight test program and include costs for those escape systems plus additional systems required for system testing. Non-recurring and test costs were increased with the complexity of the system.

Acquisition costs assume a 500 airplane production program and include costs for those escape systems. Also included are initial spares and ground support equipment. The spares factor has been increased to account for the short storage life of various propellants and initiators. The recurring production cost of the escape systems changes with system complexity.

Operations and support costs are developed using the Air Force CACE model provided in AFR 173-10 (Ref. 1), USAF cost and planning factors. A Boeing modification to this model allows the calculation of maintenance man-hours per flight hour (MMH/FH).

The MMH/FH for the baseline crew escape system is developed from current data on the F15 aircraft. The ratio of the F15 escape system MMH/FH to the F15 airframe MMH/FH is applied to the estimated airframe MMH/FH for the Model 987-230B baseline airplane. The result is the 987-230B escape system concept MMH/FH value which is translated into maintenance manning and operations and support costs. To estimate the relative maintenance requirements, a maintenance index was developed relative to the baseline system. This index is applied directly and results in the operations and support costs. As shown in Figure 5d, the value of the utility function of these costs is predicted by dividing the total

life cycle cost for the lowest cost escape system by the total life cycle cost for the proposed concept.

DEVELOPMENT RISK

The development risk for each concept may be evaluated in terms of two factors:

- o Component development status
- o Overall system development risk

The component development status accounts for escape system components and subsystems which need to be designed or modified in order for the system to operate correctly. The overall development status accounts for the complexity of the installation of the components, the difficulty of verifying overall system performance and the uniqueness of the overall operation of the concept.

The component development status may be predicted by classifying each component of the escape system in terms of:

- o Currently available (off-the-shelf)
- o Available by modification of existing components, or
- o New component development required

The utility function for the component development status is determined by summing the number of currently available components, plus one half the sum of those components available following modification and then dividing this by the total number of components and evaluated as shown in Figure 5e.

The overall system development risk is predicted by rating each concept from zero to ten (ten being best) based upon the factors previously mentioned. This rating is used to determine the utility function, as shown in Figure 5f.

NORMAL CREW FUNCTIONING

The prediction of normal crew functioning capabilities is based upon a subjective rating from zero to 10 of each concept in terms of crew comfort, mobility, vision, communication, and multiple axis acceleration support and restraint. Each of these items are highly subjective and incorporate consideration of such items as clothing encumbrances, proximity of controls and displays, visual obstructions, and general cockpit layout. The overall utility function is determined through the correlation between the subjective rating and the utility as shown in Figure 6a.

RELIABILITY

The reliability of an escape system to function as designed is primarily dependent upon the integrity of the particular design, the extent of developmental and qualification testing to which the system is subjected, level of quality control during manufacture, level of maintenance applied and simplicity of the basic concept.

In predicting the reliability of projected escape concepts it is presumed that equal effort and skill will be expended toward design, development, qualification, manufacturing and maintenance. The relative reliability of escape concepts is therefore chiefly a function of concept simplicity.

The escape system simplicity may be predicted in terms of two factors:

- o Number of distinct components
- o Number of essential escape system functions

The number of distinct components making up each concept is determined from the configuration drawings and the detail equipment lists. The utility function is determined by

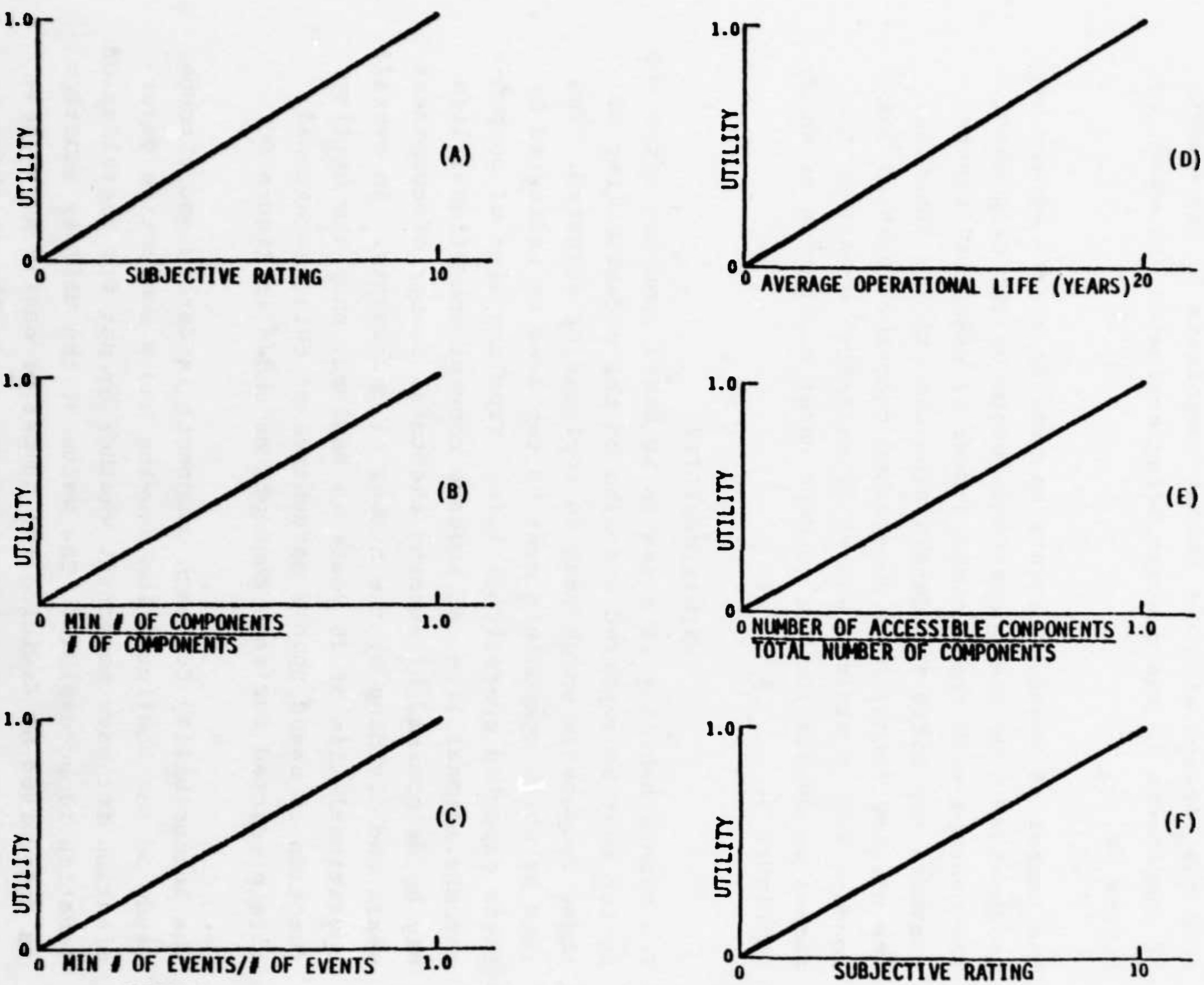


FIGURE 6 EVALUATION OF UTILITY FUNCTION

(A) Normal Crew Functioning, (B) Reliability, (C) Reliability, (D) Maintainability Life, (E) Maintainability Access, (F) Search & Rescue

considering the ratio of the number of components obtained from the concept with the fewest components to the number of components in the concept being evaluated, as shown in Figure 6b.

The number of required events to provide a safe escape may be obtained from the operational sequence for each chart. The concept with the minimum number of essential events provides the basis for determining the utility function. The utility function is determined from the ratio of the concept with a minimum number of essential events to the number of events for the concept under evaluation as shown in Figure 6c.

MAINTAINABILITY

The maintainability of a design is based upon how often the system must be repaired and also on the accessibility of those components which must be replaced or adjusted. The rate at which components must be replaced is indicated by their expected operational life. From the list of component operational life, an average concept operational life may be determined by summing the total number of component years and dividing by the number of components. An overall operational life of 20 years is desired, thus the utility function is based upon a percentage of this operational life predicted for each concept, as shown in Figure 6d.

The accessibility for each component is determined through study of the configuration drawing and a subjective determination for each component whether or not its installation location is accessible. The value of the utility function is determined by dividing the number of easily accessible components by the total number of components, as shown in Figure 6e.

SEARCH AND RESCUE

Search and rescue capabiiities are based upon a subjective rating from zero to ten (ten being best) of each concept in terms of the capability of each concept to provide adequate means to locate, provide proper survival equipment and to recover the crewmember and return him safely back to base. It is assumed, as shown in Figure 6f, that the utility function is a linear relationship between the subjective rating and the utility.

SUBJECTIVE OVERALL RATING

In addition to this detail rating system, an overview of the basic concept integrity is performed. This overview presents a subjective evaluation of each concept and rates each concept according to the following items:

- Green - system has great potential for increasing the escape success rate with little development risk
- Blue - system will save lives, however a level of uncertainty exists due to the uniqueness of the design
- Amber - system may improve escape success rate but requires more study to be sure
- Red - system has a fatal flaw in its design or operation

The combination of these two evaluation schemes provides a basis for further study, refinement and development of the best concepts.

SECTION IV
FORMULATION OF CONCEPTS

An orderly and logical method for creating new escape concepts for high performance combat aircraft was followed. The critical operating environments were defined to be high mach number, high altitude, high g operating conditions, large angular rates and high dynamic pressures. The emergency escape system must be capable of operating within the limits set by these severe environments. Initiation of escape within any of these environments leads to one or more specific critical problems. Figure 7 depicts the relationship between the operating environments and the potential problems.

Each problem was analyzed in detail to determine the fundamental forces and physical characteristics which led to the creation or continuation of the critical problem. Figures 8 to 16 show this process for each of the critical problem areas. Thus the roots of the critical problems were defined.

The basic forces and physical causes were then collected and listed. Some of these forces or causes are not modifiable and are therefore considered outside the realm of design solution. These were eliminated from further study. Those items which remained and were considered modifiable were then categorized according to the possible mode of modification as presented in Table 1. For example, one of the basic causes of injury during rapid deceleration is that the deceleration exceeds human limitations. Thus, considering the problem of human tolerance, one desired mode of modification is to provide a configuration or crientation which maximized human tolerance.

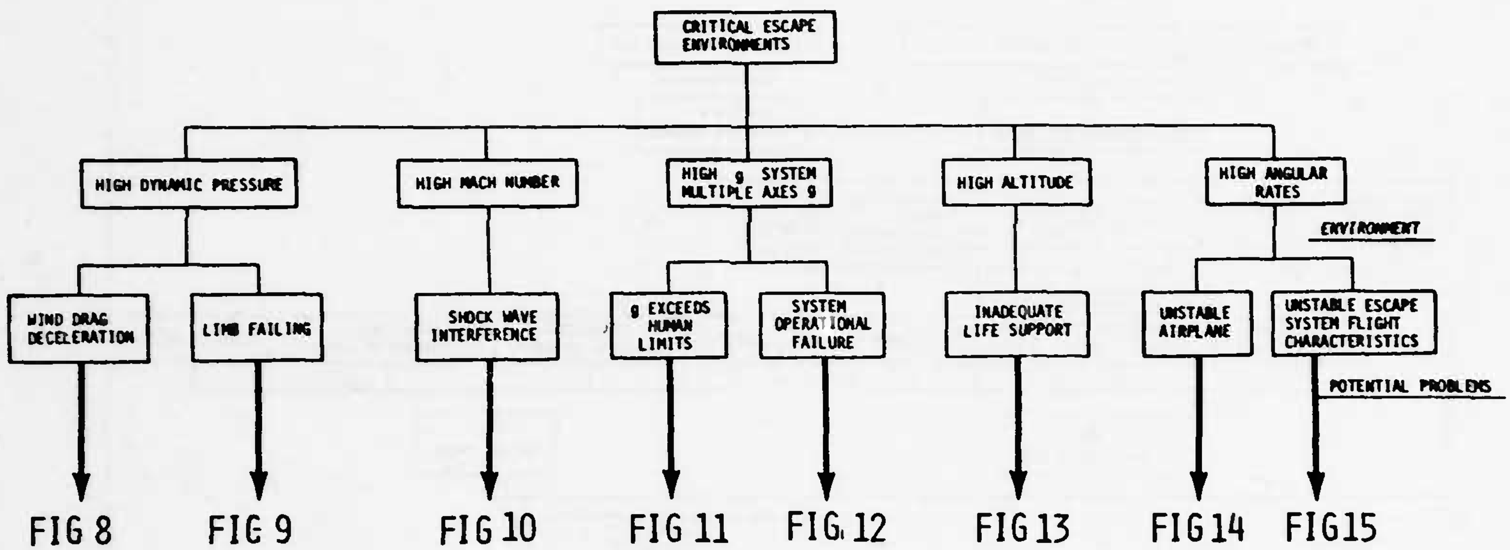


FIGURE 7 CREW ESCAPE ENVIRONMENTS AND THEIR POTENTIAL PROBLEMS

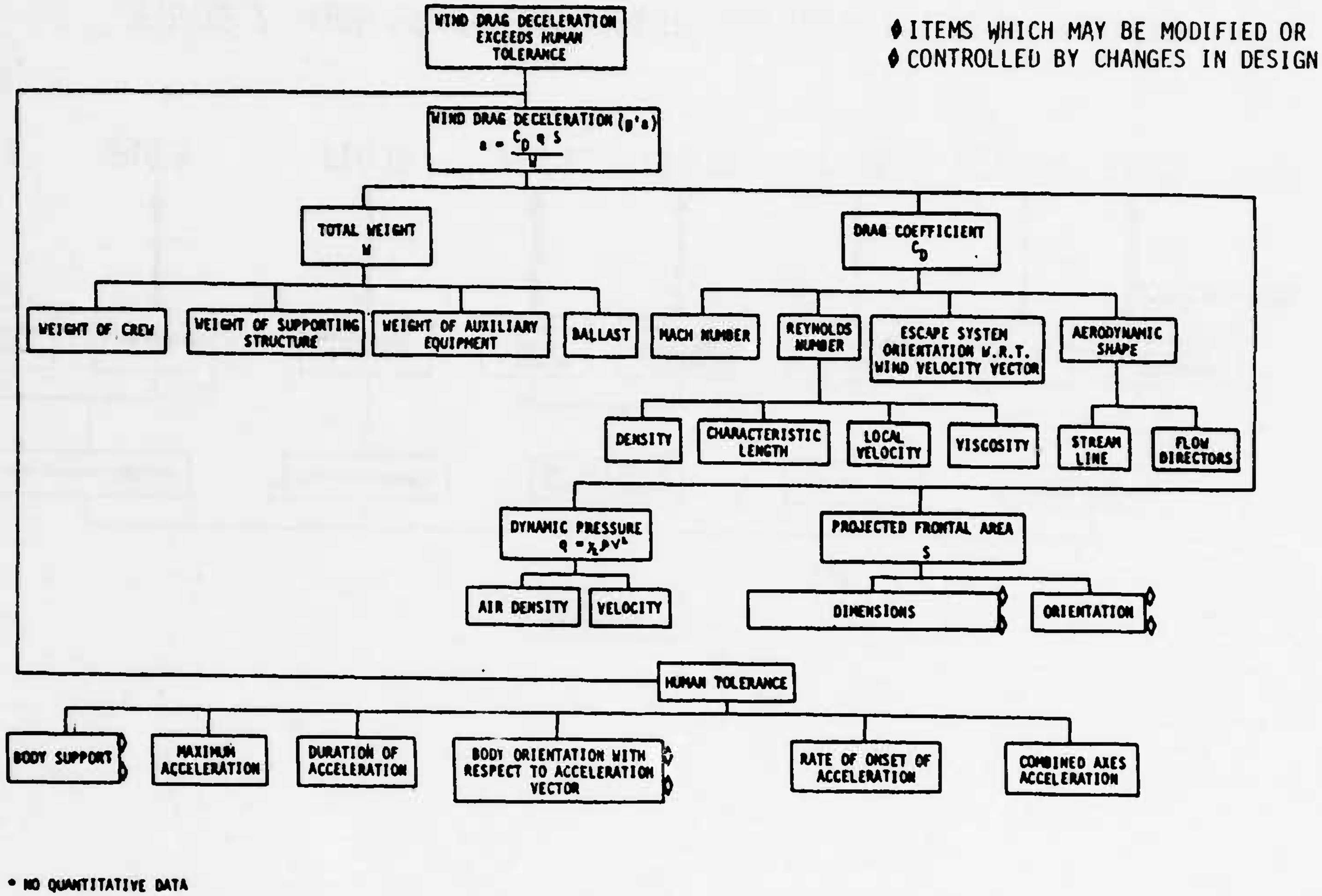


FIGURE 8 CRITICAL PROBLEM INVESTIGATION: WIND DRAG DECELERATION EXCEEDING HUMAN TOLERANCE

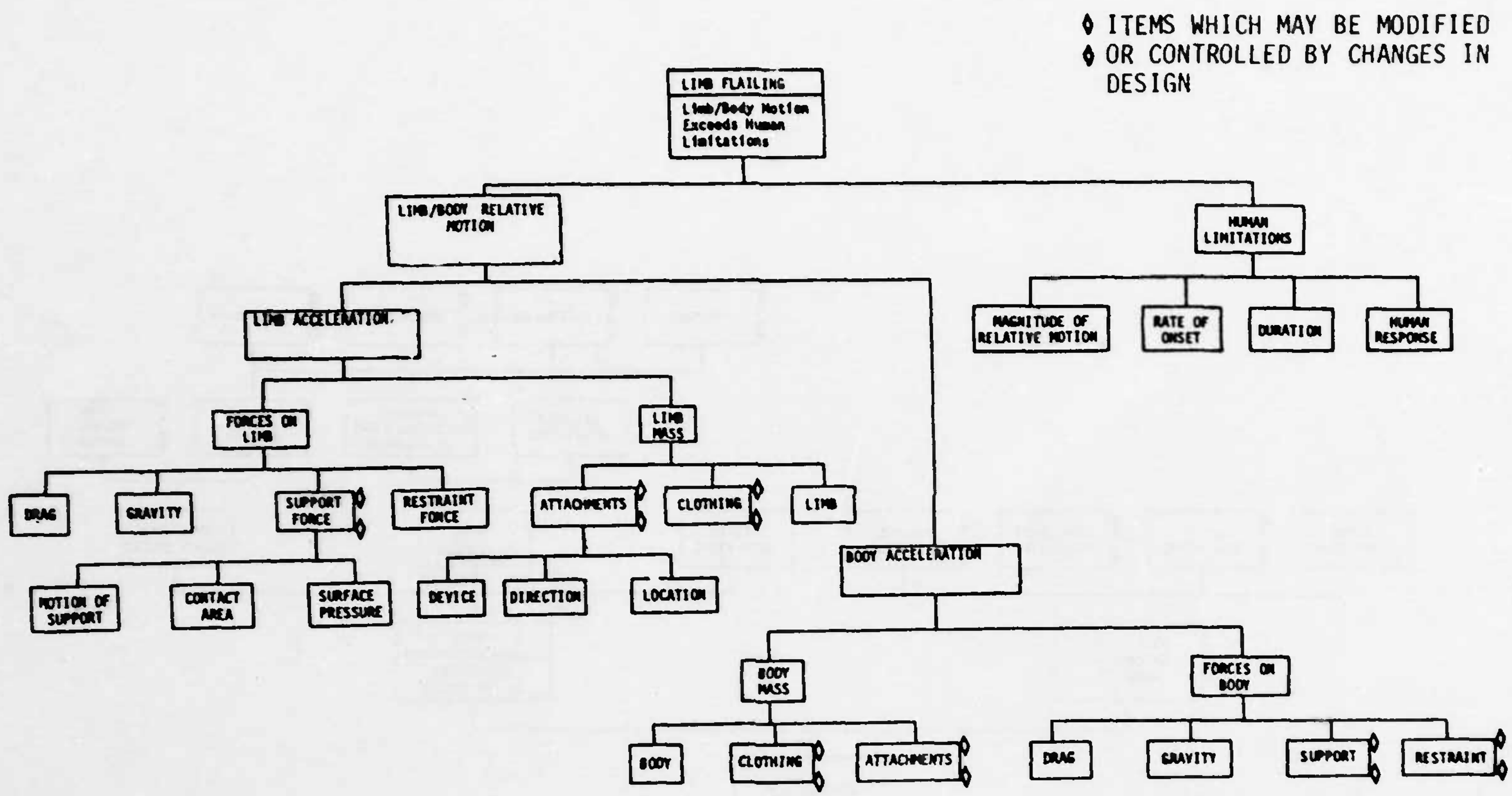


FIGURE 9 CRITICAL PROBLEM INVESTIGATION: LIMB FLAILING

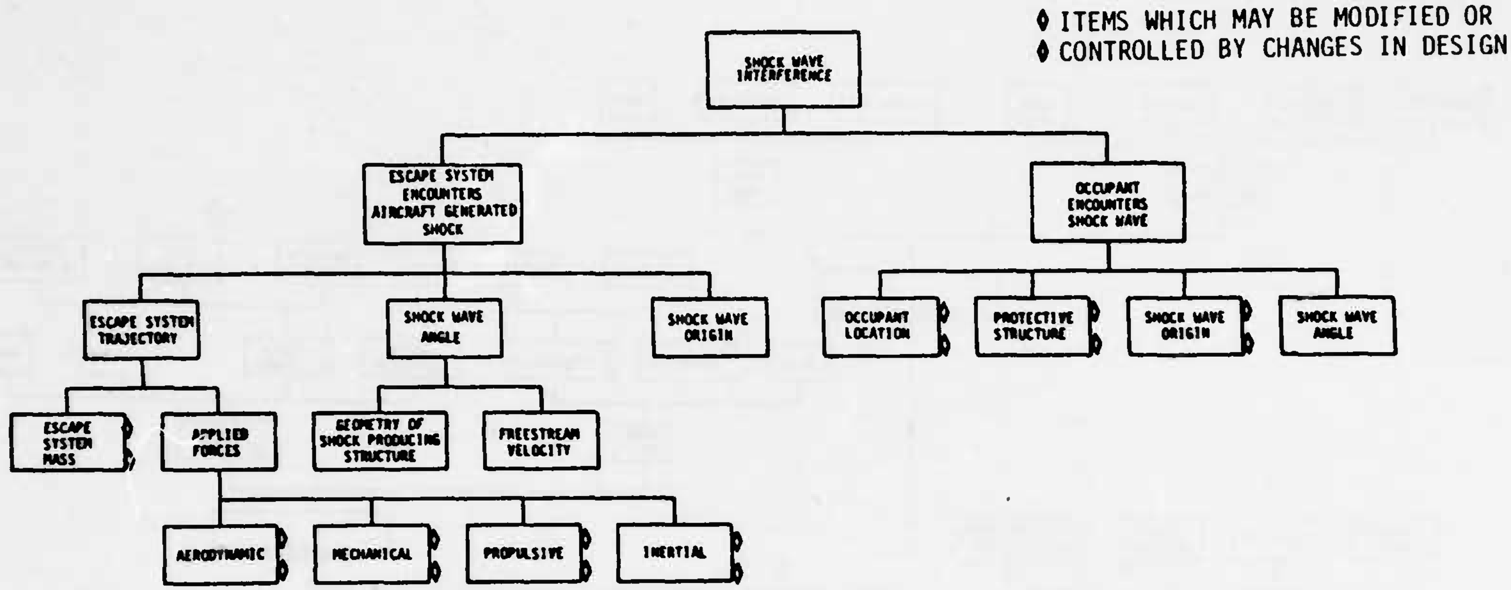


FIGURE 10 CRITICAL PROBLEM INVESTIGATION: SHOCK WAVE INTERFERENCE

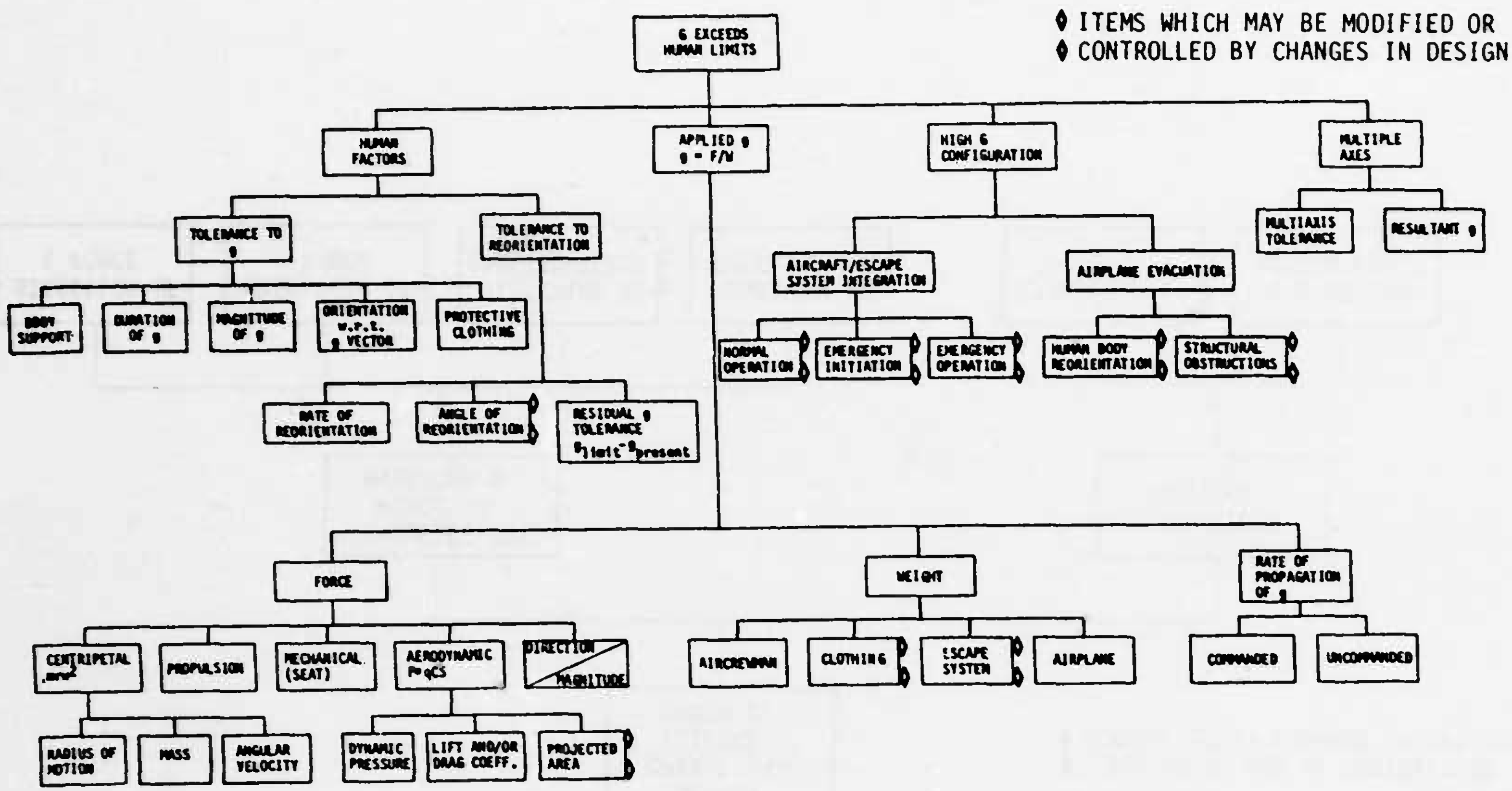


FIGURE 11 CRITICAL PROBLEM INVESTIGATION: ACCELERATION EXCEEDS HUMAN LIMITS

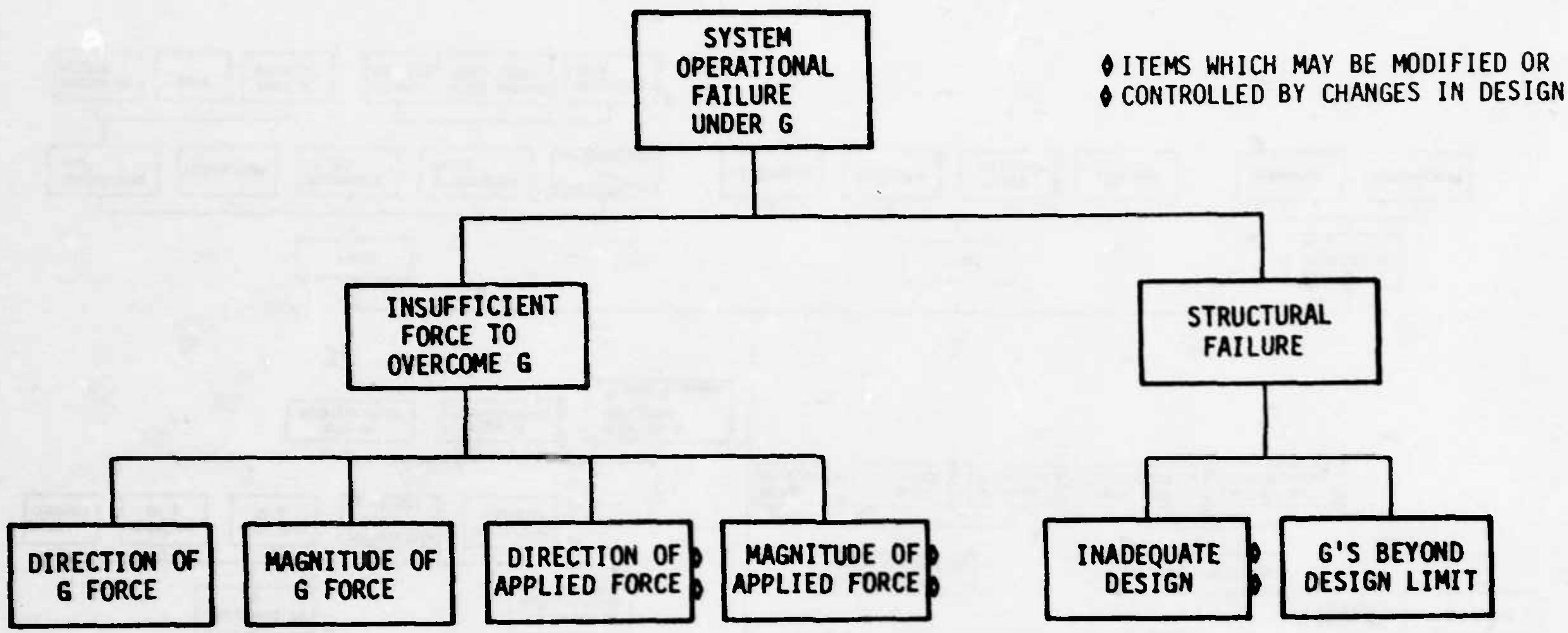


FIGURE 12 CRITICAL PROBLEM INVESTIGATION: SYSTEM OPERATIONAL FAILURE UNDER ACCELERATION

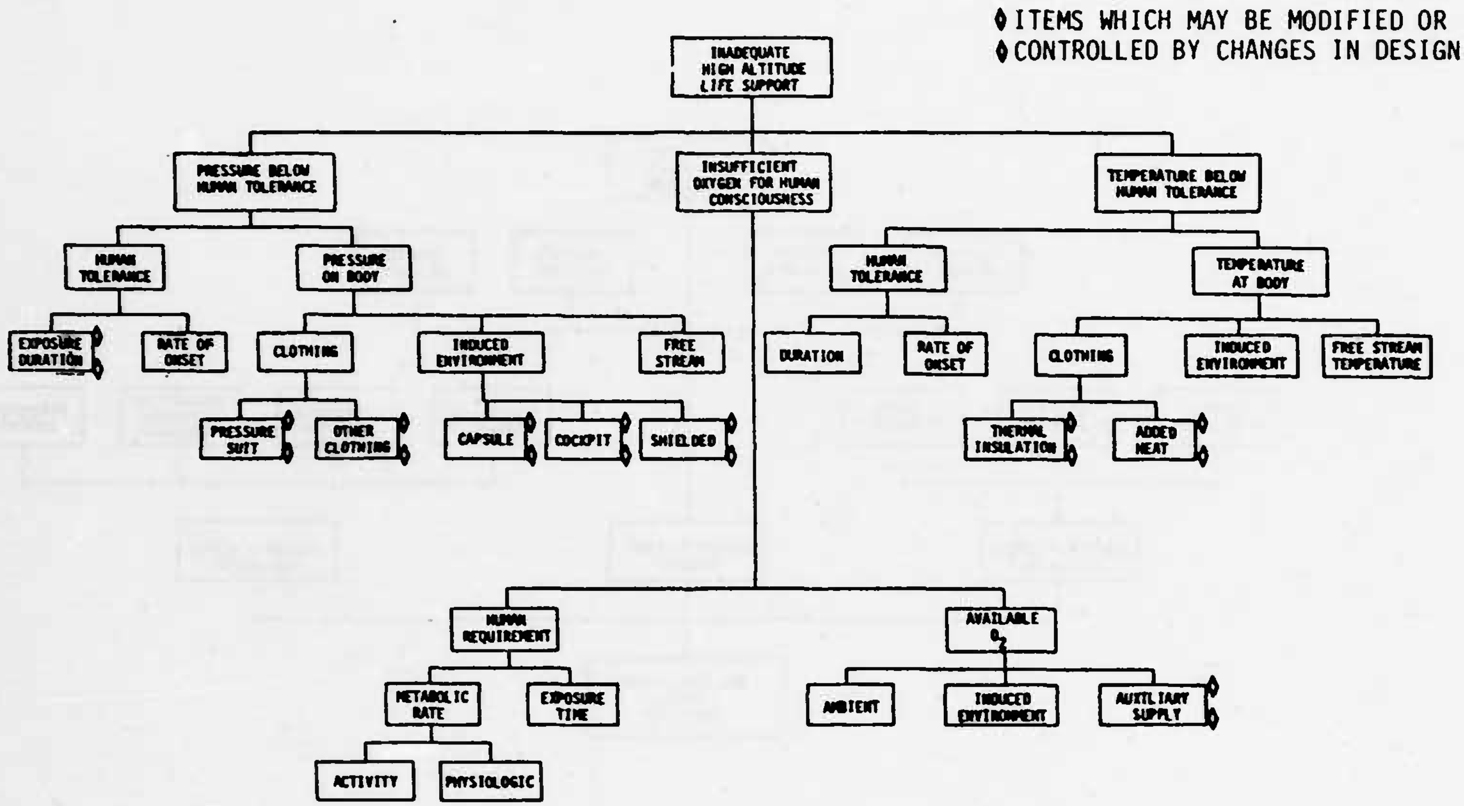


FIGURE 13 CRITICAL PROBLEM INVESTIGATION: INADEQUATE HIGH ALTITUDE LIFE SUPPORT

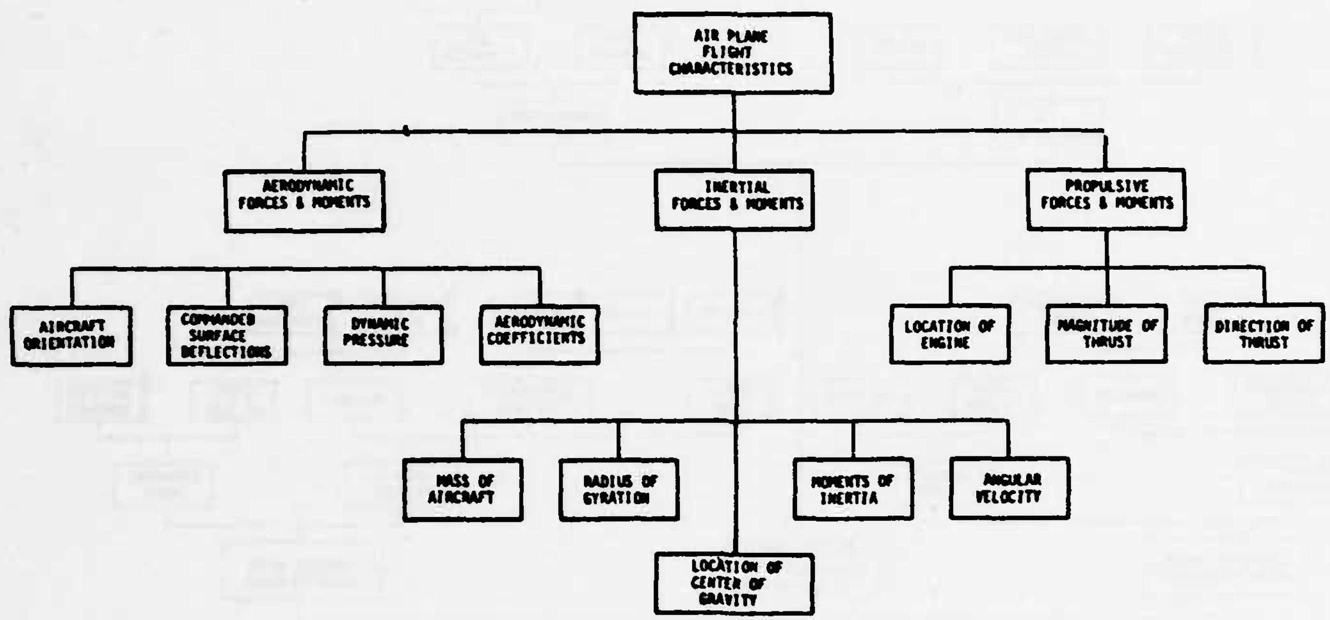


FIGURE 14 CRITICAL PROBLEM INVESTIGATION:
AIRPLANE FLIGHT CHARACTERISTICS

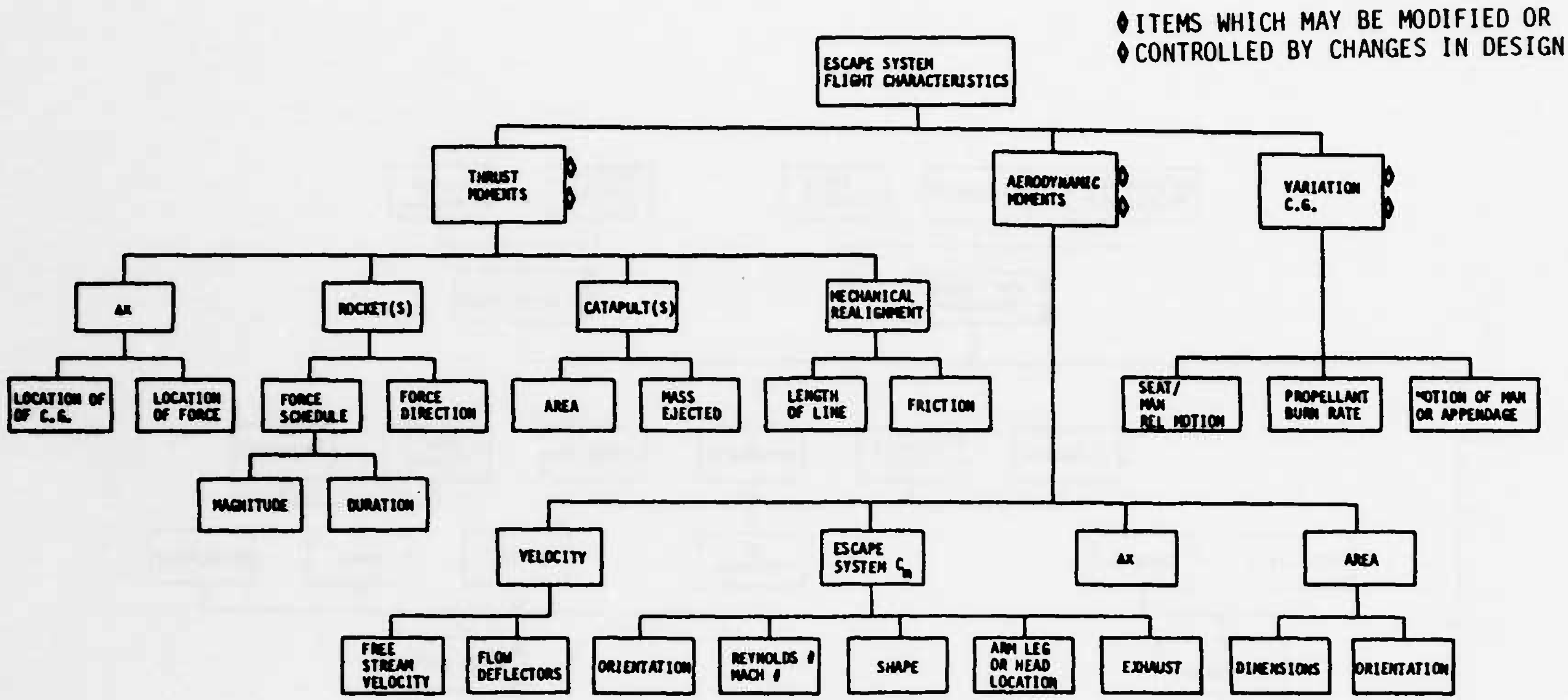


FIGURE 15 CRITICAL PROBLEM INVESTIGATION: ESCAPE SYSTEM FLIGHT CHARACTERISTICS

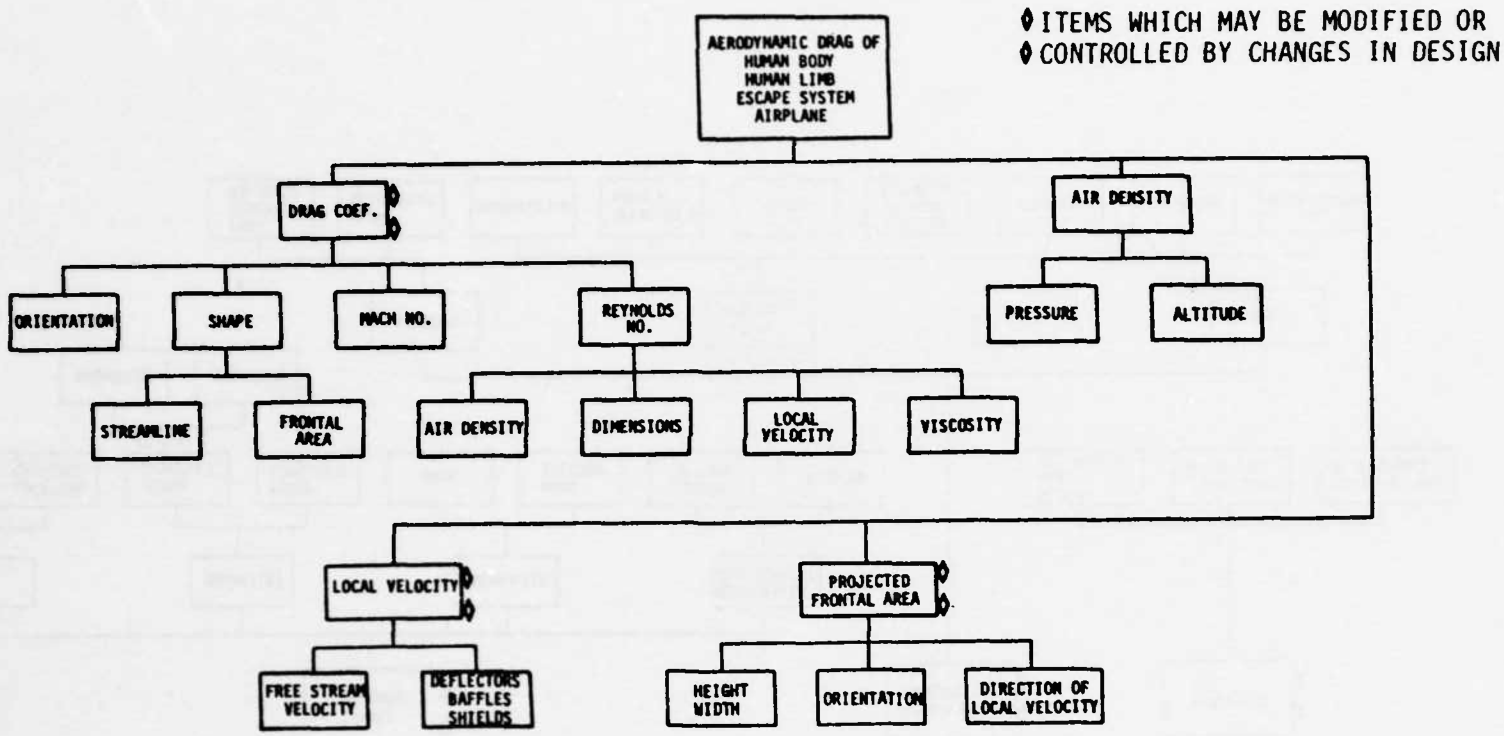


FIGURE 16 CRITICAL PROBLEM INVESTIGATION: AERODYNAMIC DRAG

TABLE 1 DESIRED FUNDAMENTAL CHANGES

ELEMENT	OBJECTIVE	HOW?
Support/Restraint	Add Increase	Add Inflatable Support Add Inflatable Restraint Encapsulate Body in Foam Add Airbag Modify Clothing to Include Restraint Add Mechanical Restraint
Crew Clothing	Increase Life Support	Add Inflation Bladders Add Auxiliary Oxygen Add Thermal Protection Add Tiedown Straps
Thrust Moments	Reduce	Change Location of c.g. Change Location of Thrust Change Direction of Thrust Reduce Duration of Rocket Decrease Catapult Propellant Decrease Catapult Pressure Area Add Compensating Thrust
Weight	Increase	Increase Strength of Seat Retain Part of the Aircraft Add Ballast Add Weight to Clothing Add Protective Devices
Aerodynamic Shape	Streamline	Add Flow Deflectors Add Afterbody Add Blowing Add Vanes Change Orientation Add Forebody Add Shock Wedges

TABLE 1 DESIRED FUNDAMENTAL CHANGES (Cont'd)

ELEMENT	OBJECTIVE	HOW?
Orientation With Respect To Wind	Modify	Add Flow Deflectors Add Stabilization Redirect Airflow
Orientation With Respect To g Vector	Modify	Rotate Seat Curve Rails Reorient Airplane Reduce g Vector
Projected Frontal Area	Reduce	Reorient Seat Reorient Man in Prone Position Reduce Structural Size
Drag Coefficient	Reduce	Orient Most Streamline Surface With Wind Add Afterbody Add Forebody Add Streamline Blowing Add Vanes

Concurrent with this investigation of the basic causes of problems is an identification of the basic building blocks or functional elements which comprise an escape system. These functional elements include the seat structure, restraint system, propulsion devices and many other items presented in Table 2. Each of these elements may be modified in some manner such as shape, weight, dimensions, function or location.

At this juncture there are then two basic lists or sets of data:

1) Fundamental problems or causes with desired modes of variation, and
2) Basic functional elements of crew escape system with feasible variations

These two lists provided a basis for the mechanization of new concepts capable of increasing the operational success rate for emergency crew escape from high performance aircraft. New concepts then were created by recombining the required functional elements or modified functional elements in a manner so as to find design solutions for fundamental problems. This combining led to a large number of potential solutions which are best categorized by their primary modification to the escape system. The resulting categories are:

- o Propulsion control concepts
- o Aerodynamic control concepts
- o Hybrid capsule/ejection concepts
- o Clothing/restraint modifications
- o Aircraft stabilization
- o Shielded systems
- o Rail modifications
- o Streamlining
- o Miscellaneous devices

TABLE 2 FUNCTIONAL ELEMENTS

FUNCTIONAL ELEMENT	VARIATION
Seat Structure	Weight, Shape, Rigidity
Restraint System	Material, Attachment, Location
Guide Rails	Angle, Weight, Interface
Life Support Equipment	Add, Delete
Propulsion	Location, Thrust Schedule, Direction, Control, Type
Sensors and Controllers	Location, Items Sensed or Controlled, Type
Canopy Remover	Type, Location
Ballistic Devices	Type, Location
Stabilization Devices	Type, Location, Dimensions
Deceleration Devices	Type, Location, Dimensions
Survival Kit	Contents, Container Dimensions, Location
Personnel Chute	Add, Delete, Type
Sequencing System	Items Energized, Power Source
Initiation System	Method of Initiation, Location
Aircrew Personal Equipment	Weight, Quantity, Stowage
Aircrew Clothing	Protection, Weight, Mobility, Comfort
Seat Adjustment	Location, Degrees
Ground Safety Equipment	Location, Protection, Operation
Escape Path Clearance	Clearance, Requirements
Escape System Severance	Type, Location, Thrust Magnitude
Fire Suppression Subsystem	Type, Location
Aircraft Interface	Location

TABLE 2 FUNCTIONAL ELEMENTS (Cont'd)

FUNCTIONAL ELEMENT	VARIATION
Aircraft Subsystems Interface	Interface Connect/Disconnect
Electrical	
Hydraulic	
Environmental Control	
Mechanical	
Avionic	
Computing	
Pneumatic	
Life Support	
Windshield	Location, Shape, Escape System Interface
Canopy	Location, Shape, Dimensions, Interface
Cockpit Closure	Vision, Location, Shape
Airflow Deflectors	Location, Dimensions, Shape, Attachment

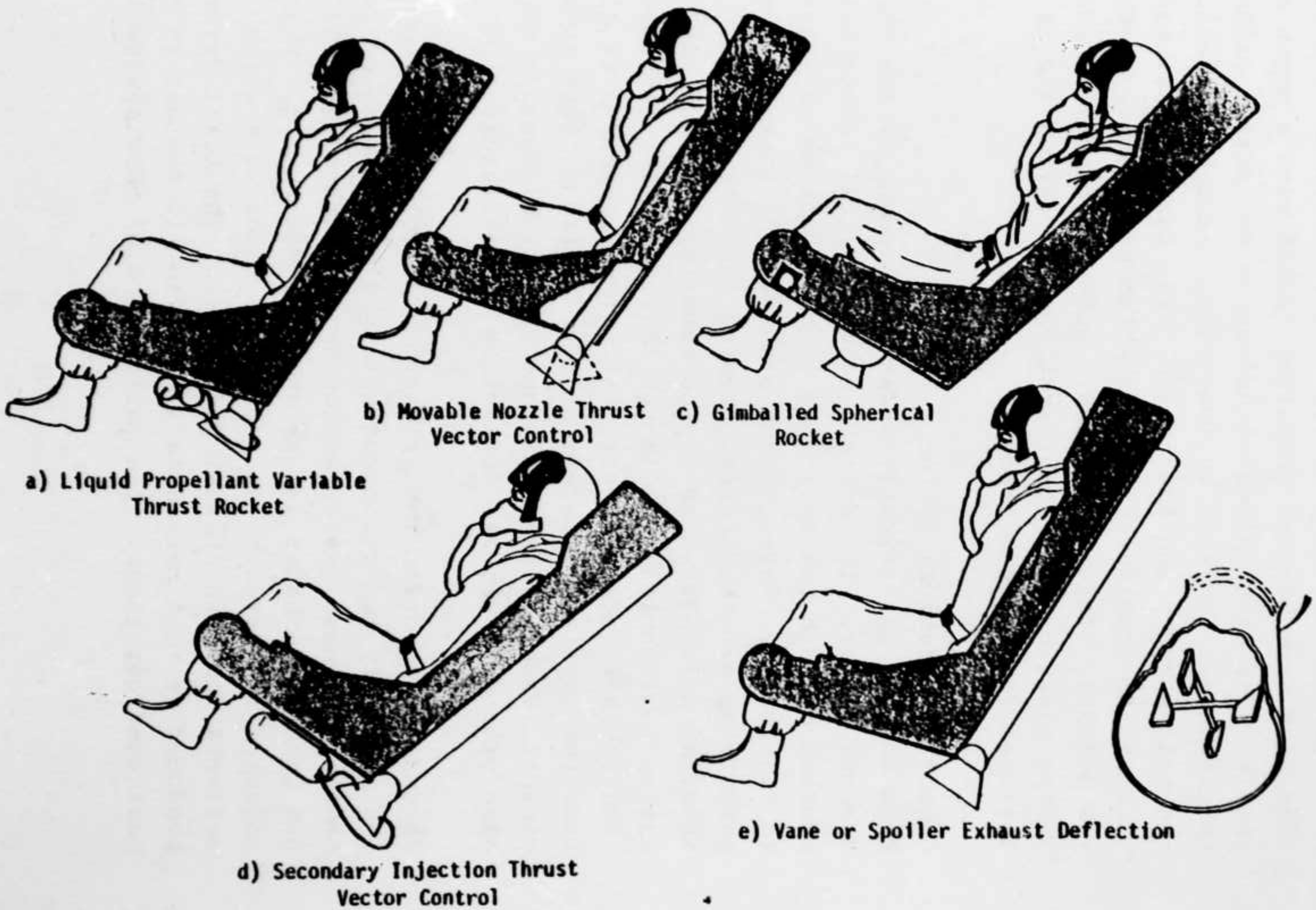
Many concepts were considered which would solve one or more of the critical problems. A brief description of the design, operation and expected performance for each concept is presented. A preliminary screening of concepts was also prepared to identify those concepts whose inherent characteristics warranted further study. The results of this preliminary objective screening are presented later.

PROPULSION CONTROL

The primary objective of propulsion control is to provide a stabilized escape platform regardless of the system center of gravity location or the magnitude of upsetting aerodynamic moments. The concepts for propulsion control are presented in Figure 17. These include a liquid propellant variable thrust rocket, movable nozzle thrust vector controlled rocket, gimballed spherical rocket with thrust vector control, secondary injection thrust vector control, and vane or spoiler exhaust deflection methods. Most of these methods have been previously studied and presented in Reference 2. Only a brief summary is included here.

Liquid Propellant Variable Thrust Rocket

This concept, as shown in 17a, utilizes high pressure liquid reactants as oxidizing and reducing agents for the sustainer rocket. The magnitude of the thrust may be accurately controlled by varying the amount of fuel available for reaction. This capability would provide a system which could be actively utilized to be responsive to the particular dynamic situation encountered during an escape situation. Due to logistics problems associated with maintaining, inspecting, storing and transporting the high pressure liquid reactants this concept was dropped from further study.



a) Liquid Propellant Variable Thrust Rocket

b) Movable Nozzle Thrust Vector Control

c) Gimballed Spherical Rocket

d) Secondary Injection Thrust Vector Control

e) Vane or Spoiler Exhaust Deflection

FIGURE 17 PROPULSION CONTROL CONCEPTS

Movable Nozzle Thrust Vector Control

This concept, as shown in Figure 17b, consists of a standard seat back mounted sustainer rocket with a movable nozzle. The internal construction of the nozzle allows its thrust vector angle to be controlled through deflection of the ball surrounding the nozzle. The control unit may be utilized to provide a reaction which counteracts pitch or yaw moments. This system has a good potential for providing ejection seat stabilization and control and is retained for further study.

Gimballed Spherical Rocket

This concept is currently under development by the Naval Weapons Center. It consists of a spherical rocket motor mounted beneath the seat on a gimballed frame as indicated in Figure 17c. This concept provides the capability of performing a fast vertical seeking maneuver from an inverted aircraft which may be beneficial in low altitude recovery situations. Although this study is concerned with low altitude recovery, the primary emphasis is placed upon the critical problems of high altitude, high speed escape. Under these conditions the movable nozzle concept also provides adequate deflection capabilities.

Secondary Injection Thrust Vector Control

The secondary injection concepts provide a means of controlling exhaust gas direction by injecting liquid or hot gas into the exhaust gas as shown in Figure 17d. This injected flow creates an additional shock wave which deflects the main exhaust gas stream. The total deflection produced by this method is limited to ± 12 degrees in the best configurations. The performance of this system in

escape system stabilization is thus degraded to an extent which makes it less attractive than the movable nozzle concept.

Vane or Spoiler Exhaust Deflection

Both the vane and spoiler configurations consist of utilizing movable surfaces which are immersed in the exhaust gas stream. Control is provided by rotating the vanes or deploying the spoilers as shown in Figure 17e. The maximum deflection for these concepts is $\pm 14^{o}$. Due to the limited deflection angle capability, this concept is not very attractive.

AERODYNAMIC CONTROL

Aerodynamic control devices are primarily used to provide ejection seat stabilization. In addition, they may be used to provide wind drag modulation. Several concepts for aerodynamic control were considered including the use of active control units in the form of movable wings and reaction jets and passive control units in the form of fixed wings, drag vanes, inflatable wings, rotating wings, and single layer fabric wings. Illustrations of these concepts are provided in Figure 18. A brief discussion of the design, operational and performance characteristics for each concept follows. Also included are comments which were the result of the initial screening procedure to select the most attractive concepts for further study.

Active Control Using Movable Wings

This concept is illustrated in Figure 18a. The stabilizing wings are mounted on top of the head rest and also along the seat sides. Prior to ejection the side mounted wings are stowed along the side and are deployed by hinging the

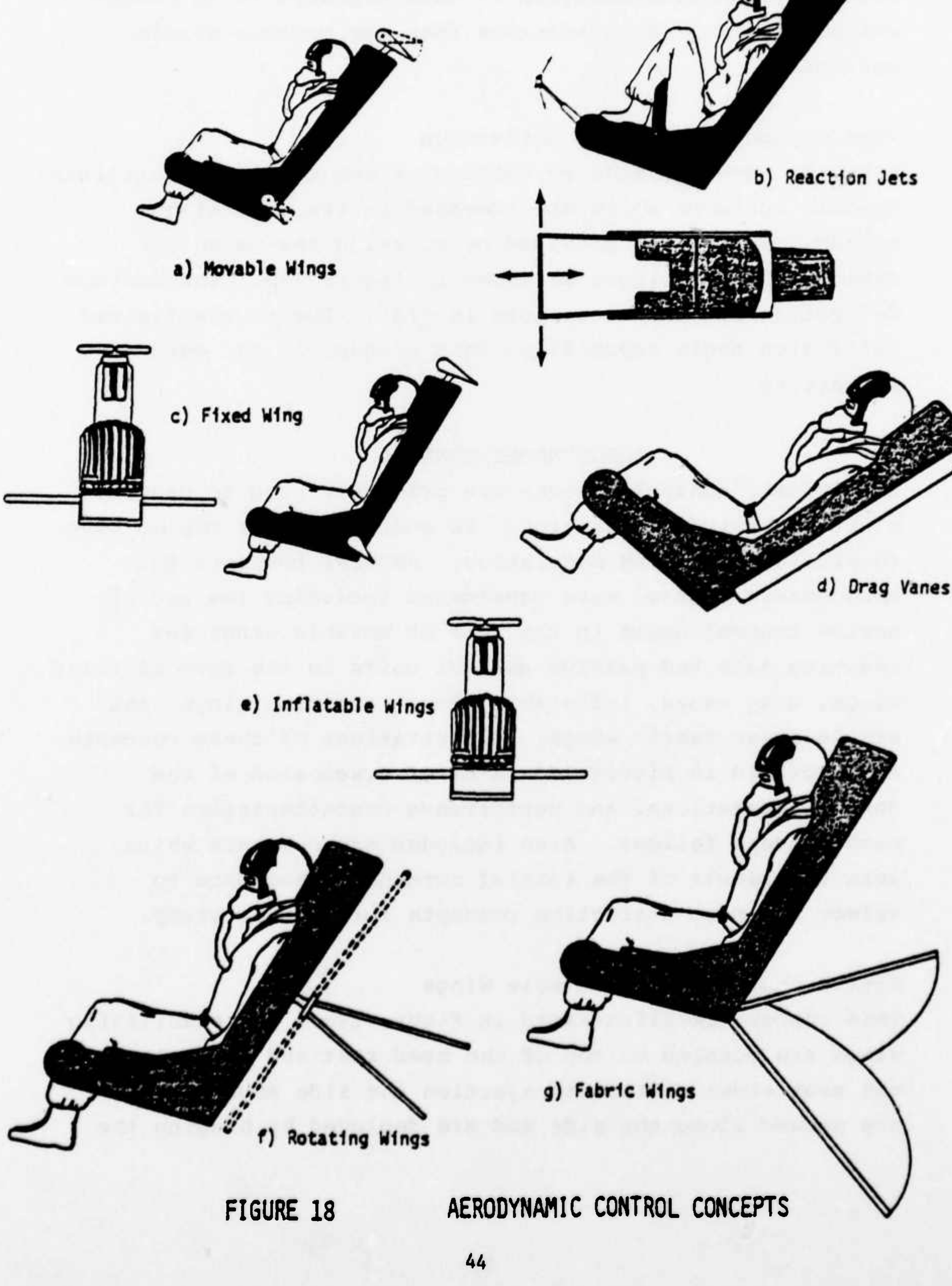


FIGURE 18 AERODYNAMIC CONTROL CONCEPTS

wings along the bottom edge. Control is provided by utilizing a seat mounted microprocessor which interprets accelerometer and gyro readings and provides control signals to the wings to counteract rotations. The system has the potential of providing stabilization at the expense of increased complexity. The concept was retained for further study.

Active Control Using Reaction Jets

Figure 18b illustrates an application of reaction nozzles to stabilize an ejection seat. The concept consists of a bar attached to the front of the seat. A series of nozzles are imbedded in the bar to provide stabilizing moments. The bar provides a split manifold for directing air upward or downward. The development risk is high due to the uniqueness of the concept. Other configurations of reaction jets are also possible. It was retained for further consideration.

Fixed Wing Stabilization

The fixed wing concept is illustrated in Figure 18c. This concept provides stationary wings attached to the seat. Through simulation and wind tunnel testing the exact location and size of the wings would be determined which would provide an inherently aerodynamically stable ejection seat throughout the range of mach numbers and dynamic pressures. The feasibility of this system is high with a relatively low development risk. The lack of moving parts makes it attractive for maintainability and reliability procedures. This concept was retained for further consideration.

Drag Vanes

Like fixed wings the drag vanes are permanently attached to the seat structure as illustrated in Figure 18d. The

primary function of the drag vanes is to shape the wake behind an ejection seat. This wake shaping will reduce the high wind drag deceleration occuring at high dynamic pressures. Like the fixed wings this concept has high maintainability and reliability factors with low development risk. It also was retained.

Inflatable Wings

Inflatable wings, as shown in Figure 18e, are fabric devices which are inflated upon ejection and entrance into the airstream. The inflation process provides a fast, positive means of deployment for stabilizing the ejection seat as soon as it departs the rails. The inflatable wing is stowed within the seat structure prior to deployment thus having a small impact on the profile of seat. Little data is available on the rigidity of these systems under conditions of dynamic pressures up to 2000 psf, thus there is a moderate development risk. The concept was retained for further consideration.

Rotating Wings

Figure 18f illustrates the application of a rotating wing unit to an ejection seat. The unit consists of a two bladed rotor spring mounted on the hub. As the ejection seat emerges into the airstream the rotor blades will extend to their full length. The spring on the hub allows the blades to close into a more streamline position as a function of the dynamic pressure. The blades provide both stabilizing moments and a modulated drag force. The concept was retained for further study.

Fabric Wings

The fabric wings mounted on booms are shown in Figure 18g.

These wings are constructed from bonded layer(s) which is attached to the boom on one edge and the seat back on the other. The boom is stowed along the seat back and deployed aft and outward. The fabric is thus stretched into the batwing configuration. The wing provides a stabilizing aerodynamic moment for correcting pitching moments without significantly increasing the overall drag. This system was retained for further study.

HYBRID CAPSULE/EJECTION CONCEPTS

The hybrid systems attain the benefits of both encapsulated and ejection systems by using the cockpit or part of it for protection while at high altitude or high dynamic pressure and the ejection seat at low altitude and slower speed. In general much of the ground impact attenuation devices may be discarded since the capsular portion is utilized only at high speed or high altitude. Following deceleration and reduction in altitude a normal ejection may be performed. The three types investigated were the separable forebody, canopy capsule, and encapsulated seat.

Separable Forebody

The separable forebody concept utilizes the nose section of the aircraft to provide high altitude and high dynamic pressure protection (see Figure 19). The separation is created by deploying the speed brake and thrust reversers on the aft body while severing the forebody skin and connecting bolts. Aerodynamic stabilization is provided by the portion of the wing which goes with the forebody. The system is estimated to provide total protection throughout the operating envelope of the aircraft. The development risk is moderate since both ejection systems and capsule systems have previously been built and operated. New methods of development and qualification testing must be

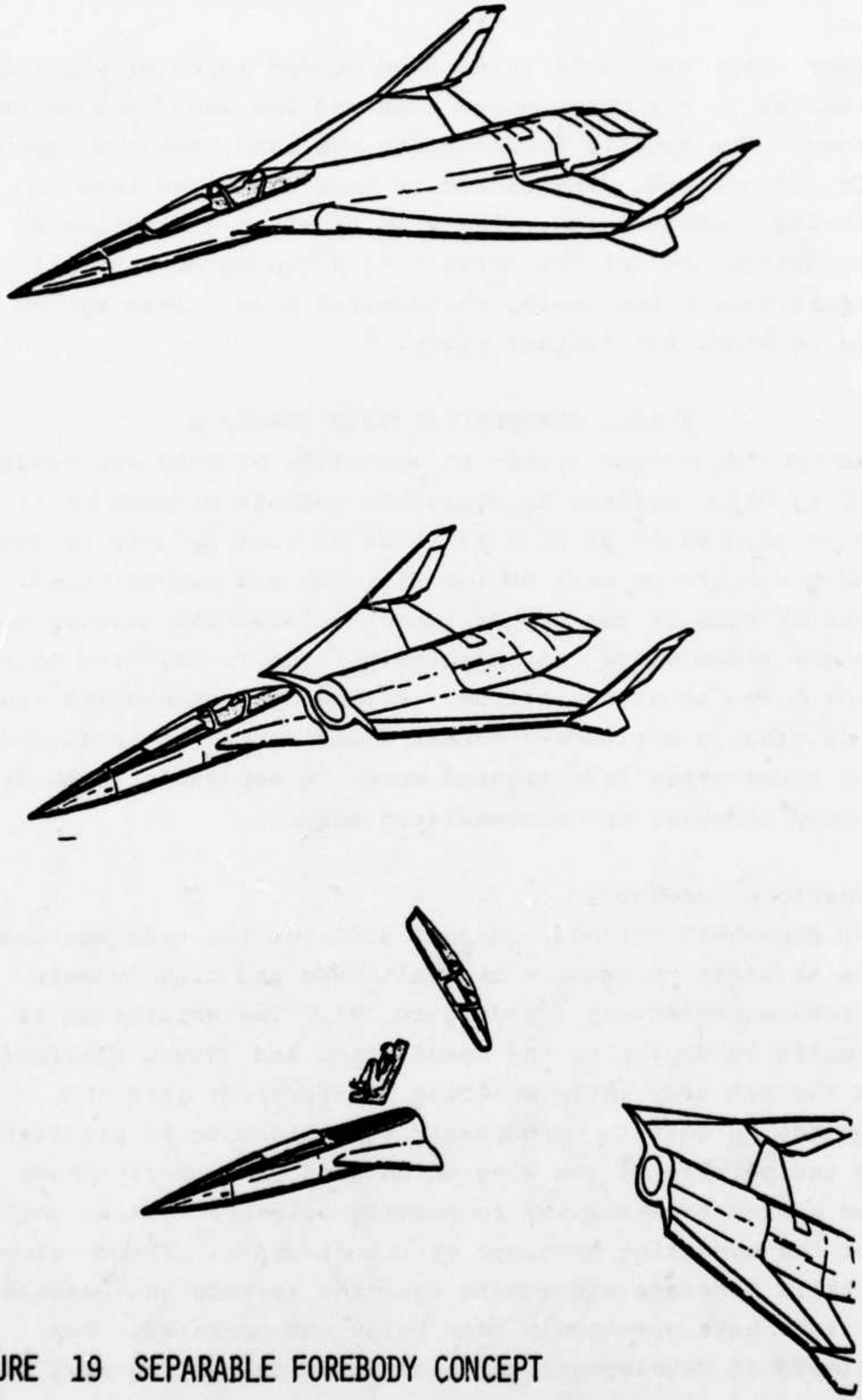


FIGURE 19 SEPARABLE FOREBODY CONCEPT

determined to validate the high altitude/high speed separation since sled tests do not accurately simulate this condition. This concept was retained for further study.

Canopy Capsule

Another means of providing protection through utilization of part of the aircraft is shown in Figure 20a. The crewmembers are rotated and elevated into the canopy. The canopy provides wind blast protection and if the bottom portion is enclosed it may also provide high altitude life support. The canopy is discarded following deceleration and a normal seat separation may occur. The canopy capsule itself has been previously studied and the development risk is moderate. The canopy jettison portion requires much more study. This concept was retained.

Encapsulated Seat

The encapsulated seat shown in Figure 20b has previously been developed and utilized. The pilot operates the aircraft in a normal manner until ejection when the encapsulating doors close. At this time the complete assembly is ejected. In the hybrid system the doors would be opened prior to touchdown and the crewmember extracted. Again this alleviates the requirement for ground impact attenuation. The reliability of this system is questionable due to its complexity. The added weight may be excessive. This concept was not retained.

CLOTHING/RESTRAINT MODIFICATIONS

Several options are available to allow special crewmember clothing to be designed such that additional support, restraint, wind protection or acceleration tolerance are provided for the crewmember. The clothing devices include a cocoon, an air or foam filled suit, a spinal support suit, liquid immersion suit and an integral restraint suit.

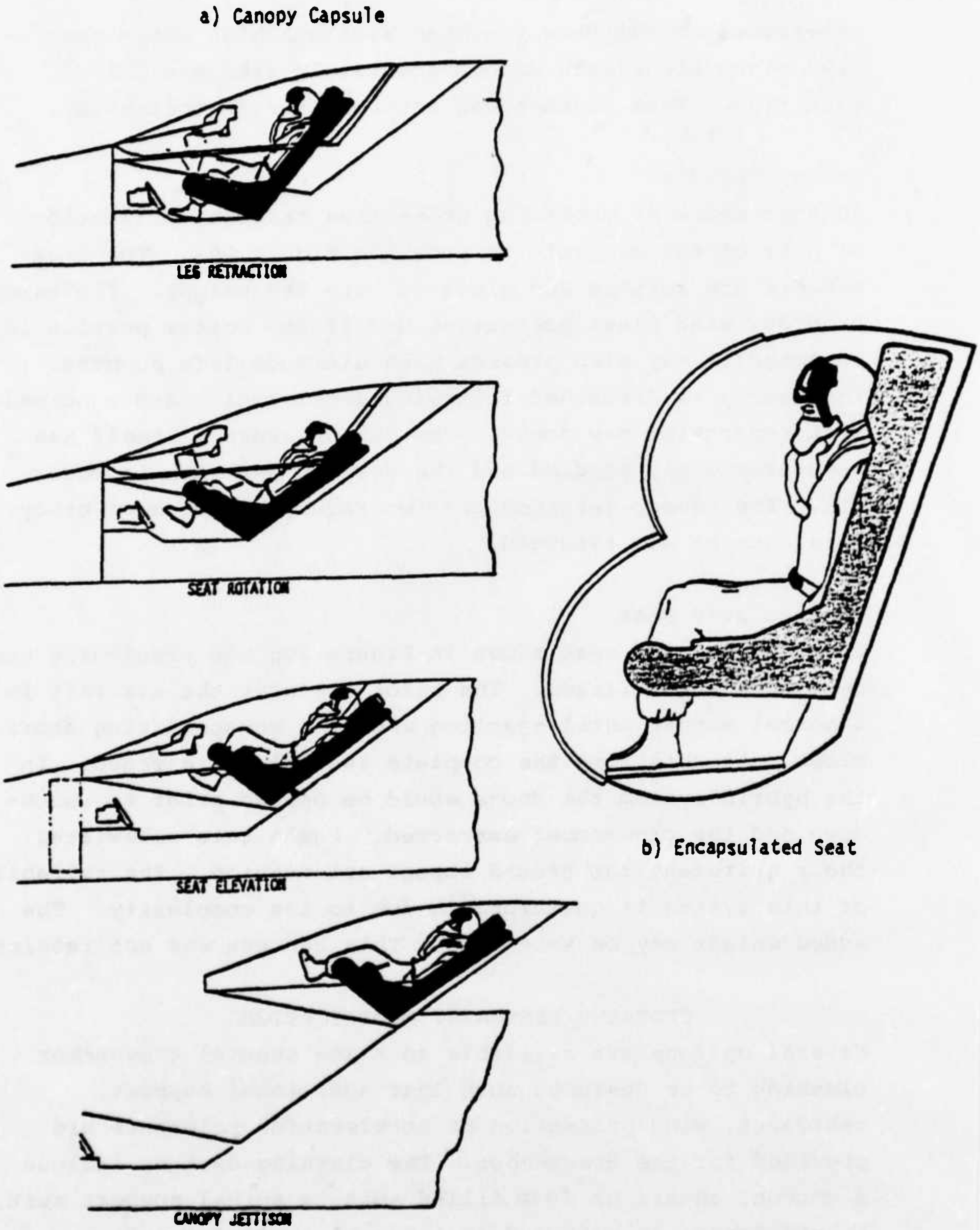


FIGURE 20 CANOPY CAPSULE AND ENCAPSULATED SEAT CONCEPTS

Cocoon

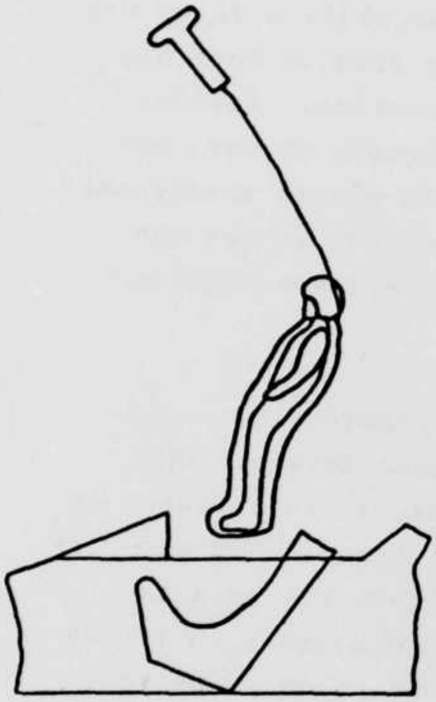
The cocoon as shown in Figure 21a is basically a large bag which inflates around the crewmember to provide both high altitude and high dynamic pressure protection. Several problems exist in trying to provide adequate oxygen, how to doff the cocoon prior to landing, how to ensure aerodynamic stability, how to inflate the cocoon and how to get the crewmember out of the cockpit. The concept was rejected.

Air or Foam Filled Suit

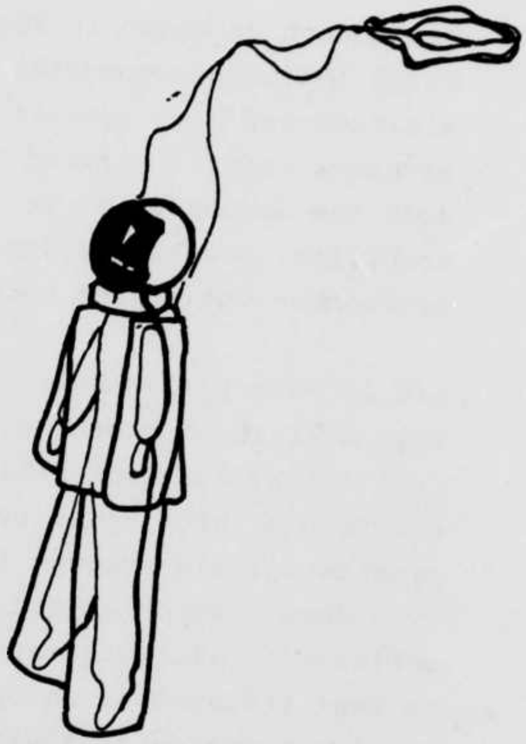
This article of clothing, as shown in Figure 21b, is a full flight suit which has two additional layers. Upon ejection at high speed or high altitude, it is inflated to provide a rigid support for the limbs, torso, head and neck. Upon deceleration or reduction in altitude the suit is deflated to allow the crewmember to land normally. It may be kept inflated as an option after landing on water to provide buoyancy or additional thermal insulation. The ventilation requirements for such a suit may provide a great encumbrance for a crewmember moving under high g loads. This concept was not retained for further study.

Spinal Support Suit

This concept, as shown in Figure 21c, provides additional support for the crewmember's spine. Rather than accepting all of the applied ejection loads at the base of the spine, some of the load is transferred by means of the support bar to the upper torso. Although this concept has potential for increasing the allowable ejection forces, this has little effect on increasing the tolerance to normal wind drag deceleration. This concept was rejected.



a) Cocoon



b) Air Or Foam Filled Suit

c) Spinal Support Suit

FIGURE 21 CLOTHING MODIFICATION CONCEPTS

Liquid Immersion Suit

This concept recognizes the increased tolerance to acceleration by allowing the body to be fully immersed in water. The suit is initially loosefitting around the body. Prior to ejection, the suit is filled with a liquid or a liquid foam. Due to the additional weight, cost and complexity, this concept was rejected.

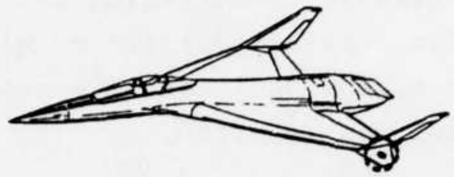
Advanced Restraint Systems

New restraint systems capable of restraining and supporting crewmembers limbs, torso and head are currently being studied. These concepts include individually tailored equipment which may be considered part of a crewmember's flight uniform and also aircraft mounted equipment generally fitting all crewmembers. These new restraint systems have the potential of eliminating limb flailing injuries and therefore they were retained.

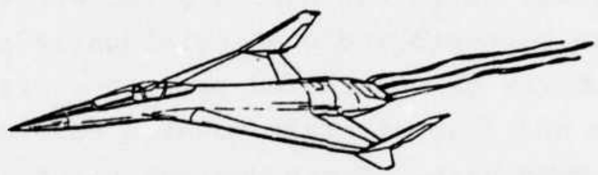
AIRCRAFT STABILIZATION

Escape from an unsteady, rapidly rotating airplane may be extremely difficult. Several methods were conceived which would stabilize the aircraft prior to ejection. These methods included the use of wing tip jet packs, deployment of aerodynamic streamers, deployment of a parachute and deployment of a parawing.

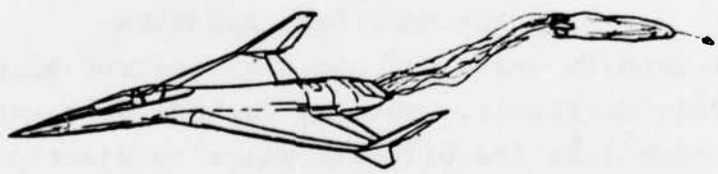
Small rocket motors on the wing tips such as shown in Figure 22a could be ignited during emergency situations to counteract excessive rolling moments. Since most solid propellant rockets do not have variable thrust capabilities there would be no means of modulating the magnitude of thrust. The general applicability of wing tip jets to counteract a wide variety of roll moments is thus not feasible. This



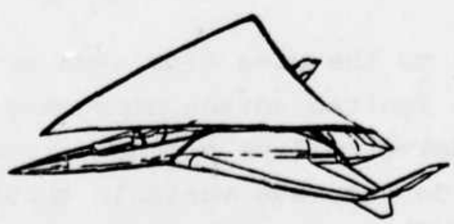
a) Wing Tip Jet Packs



b) Aerodynamic stabilization streamers



c) Stabilization parachute



d) Parawing

FIGURE 22 AIRCRAFT STABILIZATION CONCEPTS

concept was rejected.

Aerodynamic streamers as shown in Figure 22b can be quickly deployed from various portions of the aircraft to eliminate destabilizing moments. The effectiveness of these streamers under a wide range of dynamic pressures is questionable, thus the concept was rejected.

Deployment of a parachute to reduce aircraft pitch and yaw is illustrated in Figure 22c. The deployment time for most parachutes make the feasibility of this concept questionable. In addition, the wide range of possible dynamic pressures may inhibit inflation. This concept was rejected.

Deployment of a parawing is illustrated in Figure 22d. This concept considers an aircraft which may have lost an aerodynamic surface thus creating high angular rates. To alleviate this problem a parawing is deployed concurrently with severance of all remaining surfaces. This severance would eliminate all aerodynamic forces while the parawing would provide a means for re-establishing a stable aircraft condition. The complexity and the undesirability of retaining crew in a damaged cockpit make this concept impractical.

SHIELDED SYSTEMS

Operation of the escape system within dynamic pressures up to 2000 psf creates significant problems as previously described. One method of reducing some of the problems is to reduce the local dynamic pressure on and near the crewmember. Providing a shield between the crewmember and the oncoming air is one means of accomplishing this. Several shielding concepts exist including a shock probe, using the

canopy as a shield, using the windshield as a shield, providing a shield plate which is stowed under the seat, a flow diverting wedge, use of a fabric shield which is deployed in front of the crewmember, use of a protective tube during initial aircraft egress, use of a shielded extraction unit and the inflation of an air bag in front of the crewmember.

Shock Probe

The use of a shock wave generating probe deployed in front of the seat was incorporated in the Model D F104 seat as illustrated in Figure 23a. With requirements for low altitude ejection, the downward mode was eliminated, thus making the deployment more difficult. The protection capability at high mach numbers is significant and therefore this concept was retained for further study.

Canopy Shield

The canopy shield illustrated in Figure 23b provides protection by rotating the whole canopy up and placing the pilot behind this shield. Due to the lack of rigidity in the basic canopy, the high actuation forces required to rotate the canopy and the inherent instability of the system, this concept was rejected.

Retained Windshield

Retention of the windshield during the initial ejection phase is illustrated in Figure 23c. The seat and windshield are connected by a linkage and actuator mechanism. The sill beam and crossmember bar have been strengthened to provide rigidity. As the ejection seat travels up the rails, the windscreen is rotated to a position in front of the crewmember. The system as shown is inherently unstable and requires additional stabilization to ensure that no yawing

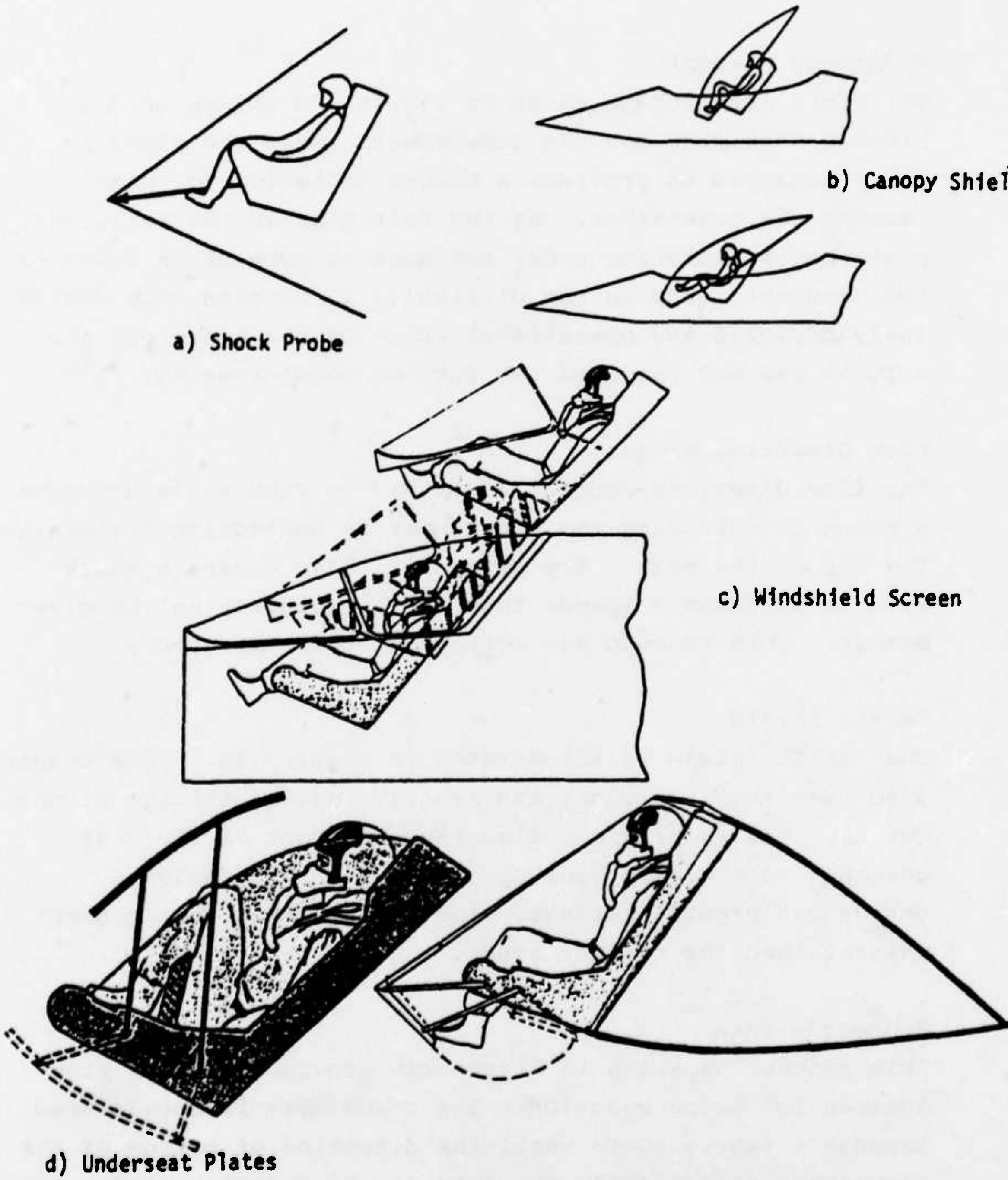


FIGURE 23 CREWMAN SHIELDING CONCEPTS

or pitching occur. The concept was retained for further consideration.

Underseat Plates

The plate and linkage shown in Figure 23d may be used to provide shielding for the crewmember. When the plate is fully deployed it provides a shaped deflector for protecting the crewmember. As the seat goes up the rails the plate begins rotation under the seat to come up in front of the occupant. Due to the difficulty in getting this device fully deployed and operational prior to the seat-rail tip off, it was not retained for further consideration.

Flow Diverting Wedge

The flow diverting wedge illustrated in Figure 23e provides a means of shielding the crewmember by deflecting air over the top of the seat. The wedge will also create a shock wave at supersonic speeds thus further protecting the crewmember. This concept was retained for further study.

Fabric Shield

The fabric shield is illustrated in Figure 24a. This concept also uses the area under the seat for normal stowage of the device. The shield is pulled taut in front of the seat occupant as the seat goes up the rails. The deployed device can provide adequate wind protection. This concept was retained for further study.

Protected Path

This concept as shown in Figure 24b provides initial protection following ejection. The crewmember is accelerated through a fabric chute until the direction of motion of the crewmember is primarily the same as the oncoming wind. Due

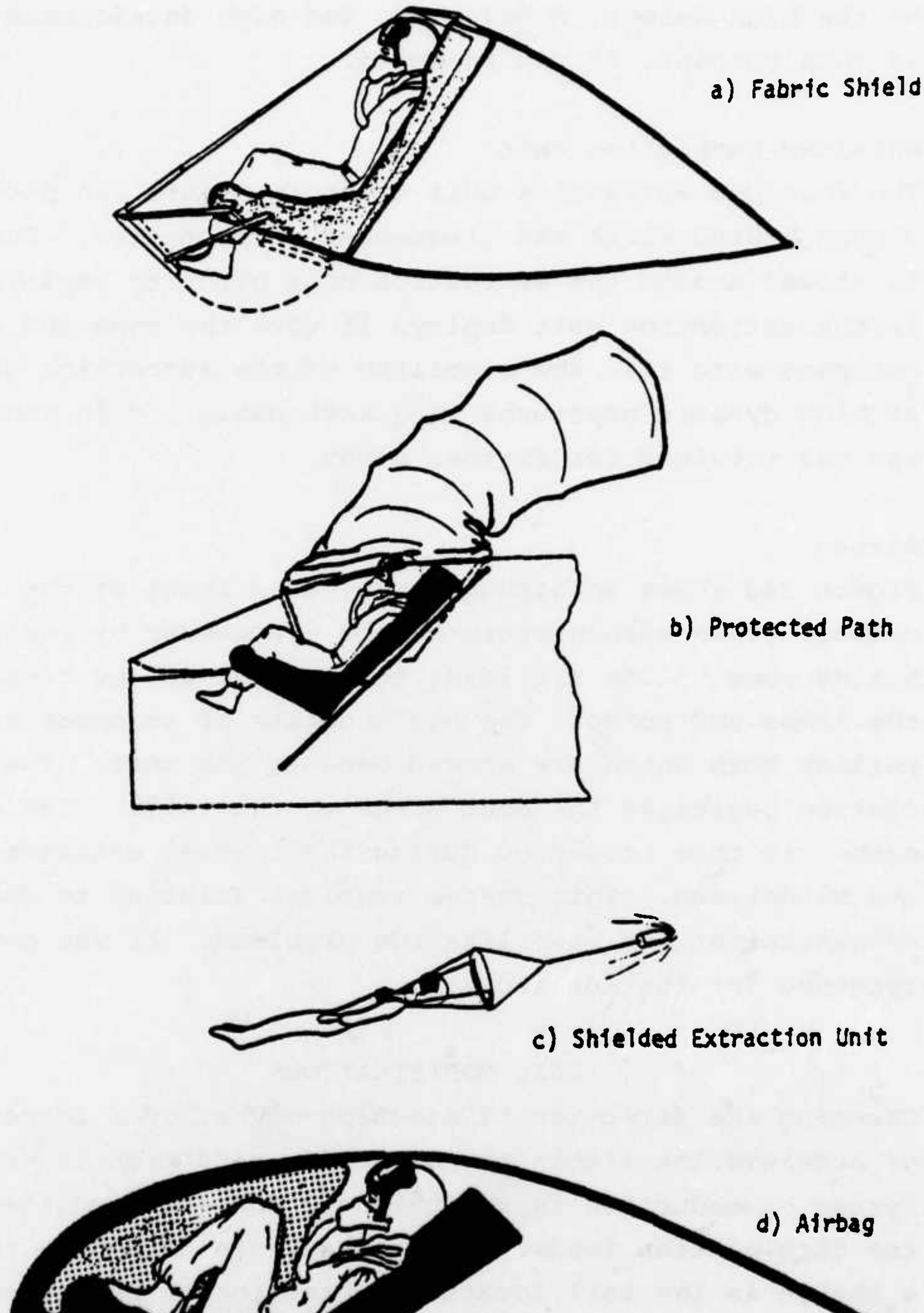


FIGURE 24 CREWMAN SHIELDING CONCEPTS

to the high weight, complexity, and high development risk of this concept, it was rejected.

Shielded Extraction Unit

The shielded extraction unit shown in Figure 24c provides a cone behind which the crewmember is protected. The cone is stowed around the extraction unit prior to deployment. As the extraction unit deploys it tows the cone and the occupant with it. The stability of the extraction unit at high dynamic pressures is questionable. This concept was not retained for further study.

Airbag

Figure 24d shows an airbag deployed in front of the crewmember. This airbag protects the crewmember by redistributing some of the air loads to the seat and by retaining the limbs and torso. The bag consists of an upper and lower portion both which are stowed beneath the seat. The inflation begins as the seat moves up the rails. The crewmember is thus protected during the initial entrance into the windstream. This system requires solution to complex mechanization and stabilization problems. It was not retained for further study.

RAIL MODIFICATIONS

Changing the direction of ejection may allow a longer period of acceleration within the aircraft, reduction in drag forces or reduction in the catapult forces to counteract the acceleration loads. Most changes in direction require a change in the rail location, direction or construction. These rail modifications may be classified as extended rails, curved rails, extended acceleration path, aft ejection, sideways ejection, downward ejection or optional ejection

direction.

Extended Rails

Rail extension as shown in Figure 25a allow a longer guided stroke for the seat to traverse. This provides a controlled situation during which other stabilization or protective devices may be deployed. The weight of this concept is critical to inclusion within other concepts. This concept was retained.

Curved Rails

Curved rails which reorient the seat in a seat pan forward position is illustrated in Figure 25b. This concept allows the crewmember to be rotated through an angle which becomes increasingly better for tolerance of normal maneuver accelerations. In addition, the projected frontal area for the seat as it enters the airstream is reduced since the seat pan is essentially facing forward. The true benefits of this seat pan forward position requires further study. The concept was retained.

Extended Acceleration

The purpose of the initial acceleration provided by the catapult is to propel the seat with a sufficient velocity to ensure clearance of all external aircraft structures. The acceleration is limited by the human tolerance to acceleration and the length of time (or distance) during which the acceleration is applied. A means of increasing the initial exit velocity without exceeding human tolerance levels is to provide an extended acceleration distance as shown in Figure 25c. Within the space confines of the cockpit the looping path is deemed most space efficient. The difficulties in mechanizing this concept as well as the

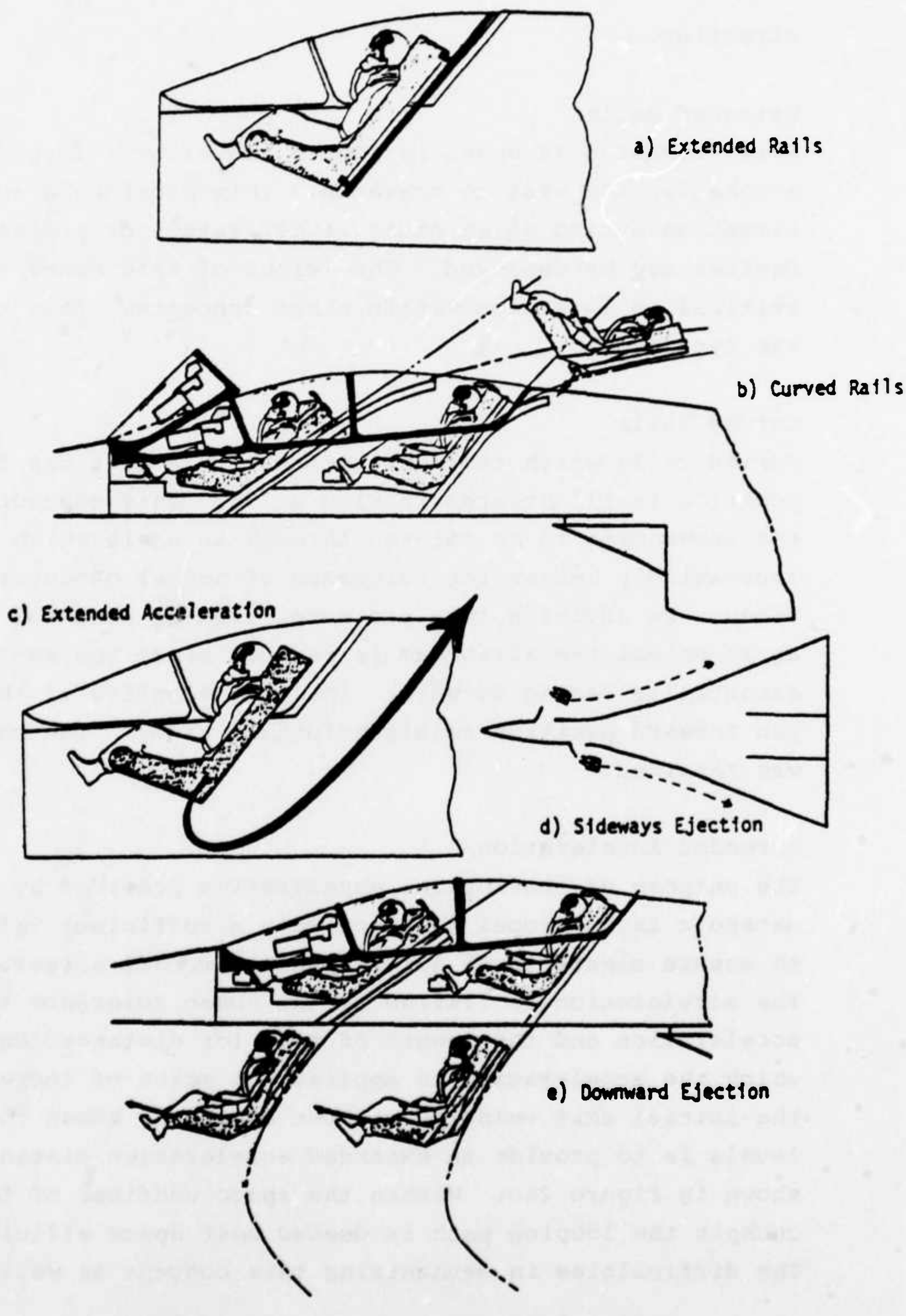


FIGURE 25 RAIL MODIFICATION CONCEPTS

adverse impact on aircraft volume make it undesirable to pursue within this study.

Aft Ejection

Providing an ejection seat which is accelerated through the center of the aircraft provides a high level of protection. The volume required and mechanization led to a quick dismissal of this concept.

Sideways Ejection

Ejecting a seat through the sides of the aircraft provide a means to eject while under high g's as shown in Figure 25d. Clearance of the wing and other external aircraft structures make this concept undesirable.

Downward Ejection

Prior to low altitude escape requirements the downward mode of ejection as shown in Figure 25e was utilized. Many advantages may be realized utilizing this method including acceleration in the same direction as high g maneuver accelerations rather than opposing them, less external structure to clear such as horizontal and vertical stabilizers, and easier deployment of protective devices which are stowed beneath the seat. This concept was retained for further study.

Optional Ejection Direction

This mode allows either upward or downward ejection depending upon the prevailing aircraft attitude, altitude, acceleration and velocity. The benefits derived from both modes are available to the crewmember. The direction may be determined by an onboard computer or selected by the pilot. The mechanizing of this concept requires additional study.

STREAMLINING

Excessive aerodynamic decelerations may be reduced through a reduction in the drag coefficient. One of the prime factors determining the drag coefficient for an arbitrary body is its aerodynamic shape. Smoothing or streamlining the body is a means of reducing the drag coefficient. Three methods of providing a smoother shape are the addition of a forebody, aftbody or reorientation of the seat to a direction allowing smoother airflow around the body.

Forebody

Figure 26a shows an ejection seat with a streamlined forebody. The forebody is an inflatable bag whose shape is predesigned to provide the greatest drag reduction. In addition, the occupant is shielded by this forebody. This concept is retained for further study.

Aftbody

A streamline aftbody is depicted in Figure 26b. This concept uses a staged deployment sequence to allow most of the aftbody to be deployed prior to seat rail tipoff. The concept has a potential for reducing drag through reduction in the wake drag. In addition, the possibility of the aftbody providing stabilization is also present. This concept is retained for further consideration.

Seat Reorientation

The basic seat structure may be rotated to present a smoother surface to the wind. This concept requires control and stabilization to retain the seat in a particular orientation with respect to the wind. The best orientation is defined through wind tunnel studies. This philosophy of optimum orientation is included in all

(A)STREAMLINE FOREBODY

(B)STREAMLINE AFTERBODY

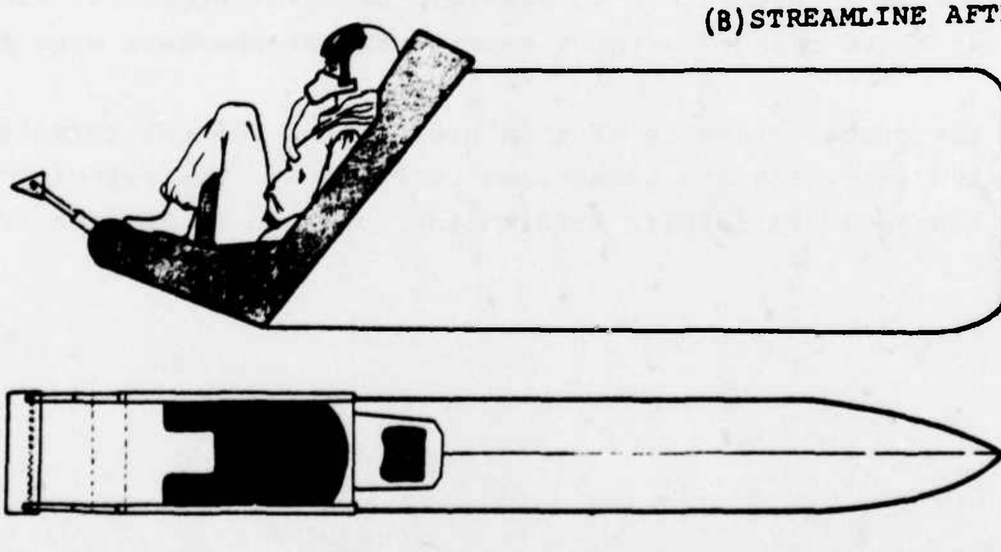


FIGURE 26 STREAMLINING CONCEPTS

stabilization concepts.

MISCELLANEOUS CONCEPTS

Two other concept classifications are included here.

Airplane Removal

All current escape systems attempt to save crewmembers by removing them from the endangered vehicle. Rather than ejecting the crewmember it was proposed to eliminate the problem by removal of the aircraft. This concept requires vast pyrotechnics and fire protection, has a high development risk and requires a high degree of airframe integration. It was not pursued further.

Decreased Local Air Density

A prime factor in the magnitude of the dynamic pressure is the value of the local air density. The density may be decreased by increasing the local temperature or decreasing the local pressure. No feasible means of providing either of these changes without harming the crewmembers were found.

The overall results of this preliminary concept formulation and screening are summarized in Table 3. The selected concepts are further studied and compared in Section IV.

TABLE 3 PRELIMINARY CONCEPT EVALUATION SUMMARY

RETAINED	REJECTED
o Movable Nozzle Thrust Vector Control	o Liquid Propellant Variable Thrust Rocket
o Active Control Using Movable Wings	o Gimballed Spherical Rocket
o Active Control Using Reaction Jets	o Secondary Injection Thrust Vector Control
o Fixed Wing Stabilization	o Vane or Spoiler Exhaust Deflection
o Drag Vanes	o Encapsulated Seat
o Inflatable Wings	o Cocoon
o Rotating Wings	o Air or Foam Filled Suit
o Fabric Wings	o Spinal Support Suit
o Separable Forebody	o Liquid Immersion Suit
o Canopy Capsule	o Wing Tip Jet Packs
o Advanced Restraint Concepts	o Aerodynamic Streamers
o Shock Probe	o Parachute Deployment
o Retained Windshield	o Parawing Deployment
o Fabric Shield	o Canopy Shield
o Extended Rails	o Underseat Plates
o Curved Rails	o Airbag
o Downward Ejection	o Protected Path
o Optional Ejection Direction	o Shielded Extraction Unit
o Forebody Streamlining	o Extended Acceleration
o Aftbody Streamlining	o Aft Ejection
o Seat Reorientation	o Sideways Ejection
	o Airplane Removal
	o Decreased Local Air Density

SECTION V
DESIGN OF SELECTED CONCEPTS

Section IV presented various concepts which were selected based upon solution of one or more of the critical escape problems. A subjective assessment of the potential capabilities for each of these selected concepts is presented in Table 4 in terms of the concepts suitability to provide adequate escape system stability at a dynamic pressure of 2000 psf, escape system operation under flight accelerations up to 10 g's, mach numbers up to mach 3, high altitude life support up to an altitude of 80,000 feet, and wind drag deceleration protection up to a dynamic pressure of 2000 psf. Only one concept has an estimated potential of meeting all requirements without further modification or combination. However, the remaining concepts may be combined to form potentially complete capability of solving all the aforementioned problems.

Prior to the combining, more screening is required to choose one concept when several similar concepts provide the same solution. As an example, the possible use of fabric wings, rotating wings or streamlined afterbody will tend to increase stability due to the addition of a device to the aft portion of an ejection seat. Although all three of these concepts have a potential for increasing the stability of the seat, the streamline afterbody also reduces the overall drag coefficient. Thus, it was chosen as the best representative of this category. Since the separable forebody concept provides estimated protection within all environments, and it consists primarily of an airframe modification, it will not be combined further.

Nine concepts, excluding the separable forebody concept,

TABLE 4 CONCEPT SUITABILITY TO MEET REQUIREMENTS

CONCEPT	STABILITY	ESCAPE UNDER G'S	HIGH MACH NO.	HIGH ALTITUDE	HIGH DYNAMIC PRESSURE
Movable Nozzle Thrust Vector Control	Yes	-	-	-	-
Active Aerodynamic Control Using Aerodynamic Surfaces	Yes	-	-	-	-
Active Control Using Reaction Jet	Yes	-	-	-	-
Fixed Wing Stabilization	Yes	-	-	-	-
Drag Reduction Vanes	-	-	-	-	Yes
Inflatable Wings	Yes	-	-	-	-
Rotating Wings	Yes	-	-	-	-
Separable Forebody	Yes	Yes	Yes	Yes	Yes
Fabric Wings	Yes	-	-	-	-
Canopy Capsule	-	-	Yes	Yes	Yes
Advanced Restraint Devices	-	-	-	-	Yes
Shock Wave Generating Wedge	-	-	Yes	-	Yes
Retained Windshield	-	-	Yes	-	Yes
Fabric Shield	-	-	Yes	-	Yes
Extended Rails	Yes	-	-	-	-
Curved Rails	-	Yes	Yes	-	Yes
Downward Ejection	-	Yes	-	-	-
Optional Ejection Direction	-	Yes	-	-	-
Forebody Streamlining	-	-	-	-	Yes
Streamlined Aftbody	Yes	-	-	-	Yes
Seat Reorientation	-	Yes	-	-	Yes

provide stabilization capabilities which meet the stability requirements during all or part of the escape sequence. Both the active aerodynamic control and fixed wing concepts provide a stabilizing force which is proportional to the dynamic pressure. The fixed wing concept likewise provides this capability without the added complexity of the control system; thus, the fixed wing was chosen as the representative for this category. Rigid fixed wings were compared with the inflatable wings. The rigid wings were retained due to the greater certainty that they could withstand the high dynamic pressures. The rotating wings concept and fabric wings concept were not retained for the reasons previously stated.

Escape under g loadings up to 10 g's may be accomplished through use of curved rails, downward ejection, optional ejection direction, or seat reorientation. The downward ejection was not retained due to the incorporation of this mode within the optional ejection direction concept.

The fabric shield and retained windshield concepts both provide protection at high mach numbers by incorporating the use of a full shield in front of the crewmember. Both are estimated to provide equivalent protection; however, the retained windshield is a little simpler, thus it was chosen as the best representative of these concepts.

The separable forebody concept and the canopy capsule concept provide capabilities of meeting the high altitude life support requirements; however, they are both highly dependent on integration within the aircraft and do not lend themselves to incorporation within other concepts. Therefore the newly combined concepts will be configured utilizing latest technology life support clothing and equipment with the capability of sustaining the pilot from

the time of escape initiation to the time of touchdown.

High dynamic pressure environment requires a system which eliminates limb flailing and protection from excessive wind drag deceleration. Eleven concepts provide protection from one or both of these problems. Both the drag reduction vanes and streamline afterbody reduce aerodynamic drag through shaping of the wake behind the seat. Since the streamline afterbody also provides stabilization it was selected as the best representative. The streamline fore-body is similar to the retained windscreen in that it also shields the crewmember and presents a streamline shape to the oncoming flow. The retained windscreen was kept as the best representative due to the better utilization of existing aircraft structures.

The remaining concepts are now combined in a manner which will allow protection throughout the operating environment of the aircraft. The combining process allows each repre-sentative concept to be configured into an overall escape system.

The above process leads to thirteen mechanization concepts with a potential of solving some or all of the escape problems. These concepts are:

- o Movable nozzle thrust vector control
- o Active control using reaction jet
- o Fixed wing stabilization
- o Separable forebody
- o Canopy capsule
- o Advance restraint devices
- o Shock wave generating wedge
- o Retained windshield
- o Extended rails

- o Curved rails
- o Optional ejection direction
- o Streamlined afterbody
- o Seat reorientation

A review of the above thirteen remaining concepts for mechanization led to the selection of five preliminary design candidates which were then configured in terms of installation drawings. The purpose of these configuration drawings was to define the airframe/escape system integration requirements and interfaces, illustrate volume and weight penalty, establish subsystem and component requirements, and identify possible component installation locations. The ability to perform normal crew functions was also estimated from these configuration drawings, including crew mobility, intercrew communication, vision and comfort. The five combined concepts which were selected for preliminary design are:

- o Separable forebody
- o Optional ejection direction
- o Retained windshield with streamline afterbody
- o Curved rails with thrust vector control
- o Canopy capsule

SEPARABLE FOREBODY

The separable forebody concept was previously estimated to provide full protection within the limits of the five critical problems. The design also inherently includes stabilization by means of fixed wings in the form of deployed access door, and a portion of the aircraft wing. During the normal ejection phase the ejection seat is stabilized by means of the movable nozzle thrust vector control system.

The separable forebody operates in two phases depending upon the altitude and airspeed. Low speed, low altitude recovery is provided through use of current state-of-the-art ejection seats. At speeds greater than 350 KEAS or altitudes greater than 40,000 feet, the forebody of the aircraft is passively separated by means of cutting the connecting structure between the forebody and the aircraft and concurrently decelerating the aft section through automatic deployment of the speed brakes and the engine thrust reversers. The forebody then decelerates and descends to 20,000 feet at which time the crewmember either manually ejects or is automatically ejected following sufficient warning. The ejection sequence begins with restraint system tightening, canopy jettison, and display panel and windshield erection to provide a clear ejection path. The aft pilot is ejected first followed by the forward pilot after a slight time delay to ensure that neither will interfere with the other during escape. During the initial phase of operation the ejection seat is stabilized by means of a movable nozzle thrust vector control system. A drogue chute is used to decelerate the ejection seat and also to extract the crewmember from the seat. The crewmember never rides the forebody all the way to touchdown. This sequence of events for the separable forebody is illustrated in Figure 27.

The installation drawing, Figure 28, illustrates some of the special design features for the separable forebody concept. Structural elements at the separation plane are the longerons and the airframe outer skin. To accomplish forebody separation the longerons are separated by means of activating the explosive bolts connecting them and the skin is severed by activation of an encapsulated primer chord

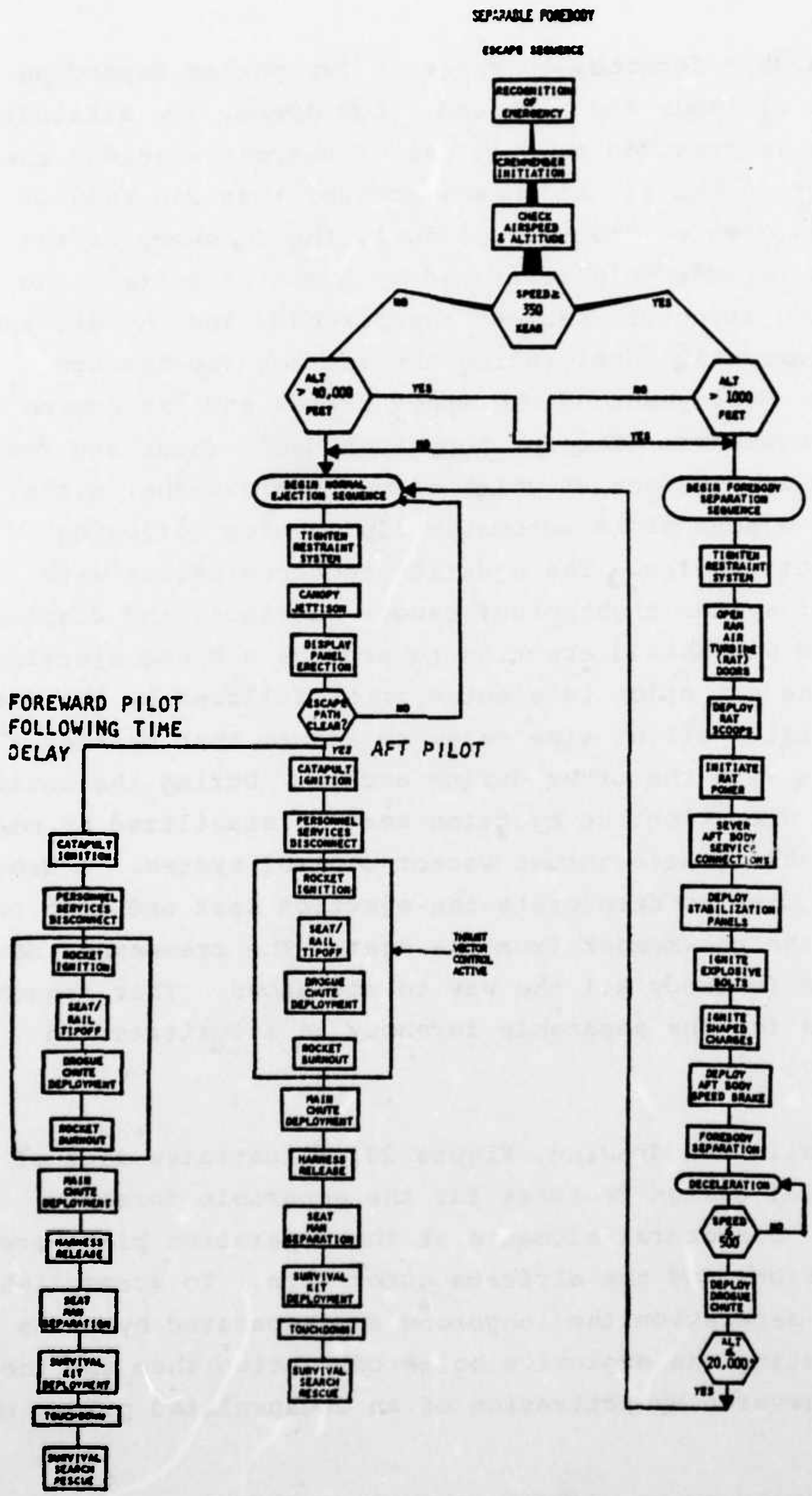


FIGURE 27 SEPARABLE FOREBODY ESCAPE SEQUENCE

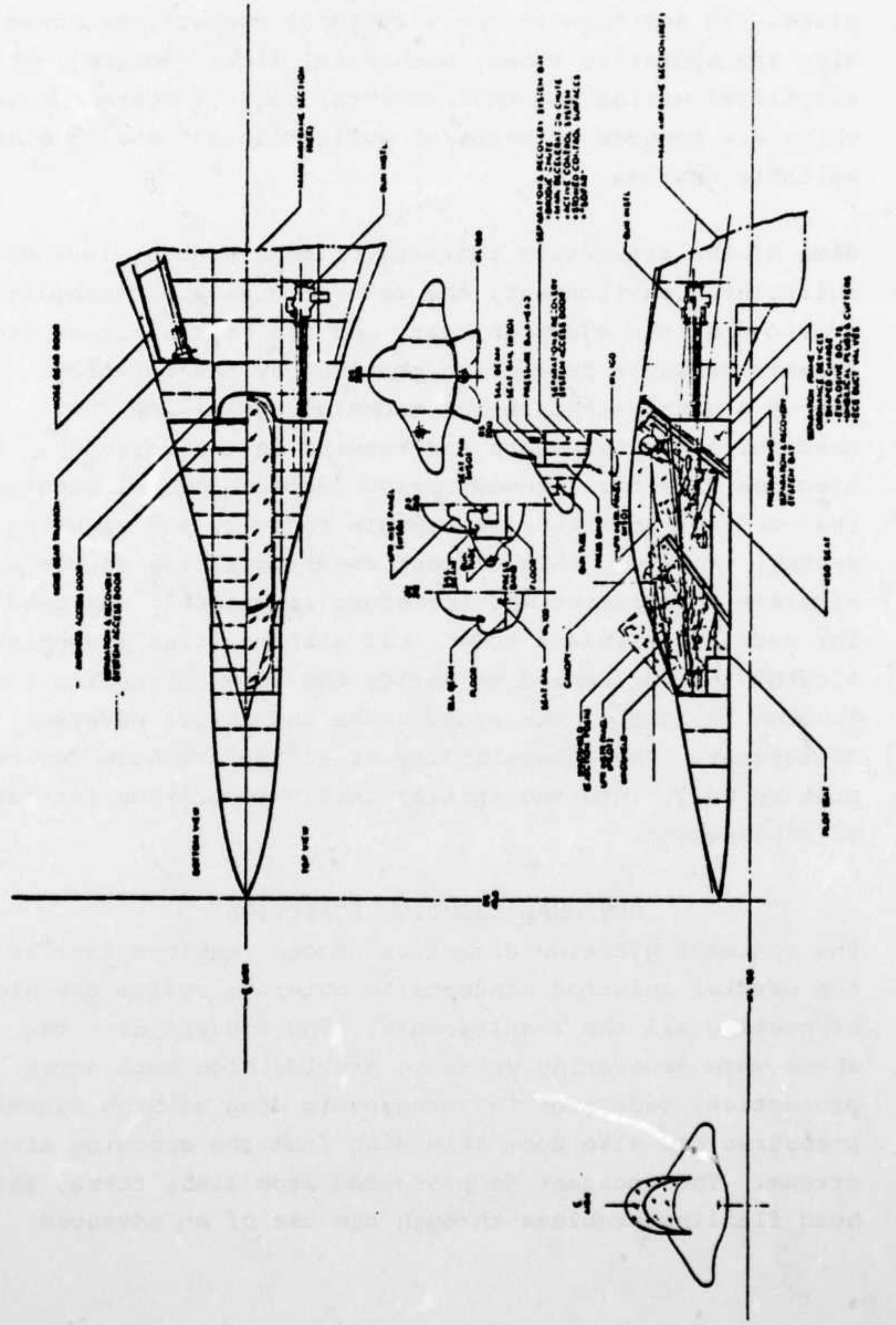


FIGURE 28 SEPARABLE FOREBODY CONFIGURATION

embedded in the skin along the periphery of the separation plane. In addition to the structural connections there also are hydraulic tubes, mechanical links, control cables, electrical wiring and environmental control system ducts which are severed by means of guillotine cutters or other suitable devices.

Some of the attractive features of this concept include the shirtsleeve environment, the zero-zero escape capability provided by the ejection seat, and the high altitude high dynamic pressure protection provided by the forebody. The use of a passive separation technique nullifies the need for heavy thrusters and rockets on the forebody. The ejection from the forebody prior to touchdown eliminates the need for an extensive capsule recovery and righting system. However, this concept requires a high degree of aircraft integration and therefore is uniquely designed for each new airplane model. It also requires a sophisticated testing method to verify the forebody separation through the use of the speed brake and thrust reverser deployment. The accessibility of all pyrotechnic devices must be built into the initial design to provide for ease of replacement.

OPTIONAL EJECTION DIRECTION

The optional ejection direction concept employs four of the partial solution concepts to obtain a system capable of meeting all the requirements. The concept uses the shock wave generating wedge to provide high mach number protection, reduction in aerodynamic drag at high dynamic pressures and also some shielding from the oncoming airstream. The occupant is protected from limb, torso, and head flailing problems through the use of an advanced

restraint system which prevents motion of the body elements during high dynamic pressure conditions. The seat is stabilized in pitch and yaw initially by means of a cool gas reaction jet control system mounted on the wedge in front of the crewmember. For escape while under high g maneuvers a downward ejection option is provided whereas under most other conditions a normal upward ejection is performed.

The escape sequence may be initiated by either crewmember; however, upon ejection the aft pilot goes first followed by the forward pilot after a slight time delay. Following initiation the proper direction is selected by a microprocessor mounted on each seat. A warning indicating direction of ejection is provided to each crewmember followed by either floor panel severance or canopy jettison depending upon the direction of ejection. For a downward ejection the restraint system is tightened followed by downward catapult firing. As the base of the seat emerges from the aircraft the shock wedge is extended and the reaction jet control system is initiated. The downward mode doesn't utilize a sustainer rocket due to the absence of structural clearance problems. The seat is initially stabilized by the reaction jet control system and upon deceleration is stabilized by a drogue chute. The shock wedge provides a streamlining effect at high dynamic pressures and thus reducing the drag coefficient and ultimately the wind drag deceleration. The upward ejection follows a similar sequence as shown in Figure 29, except that after initiation and canopy jettison the forward display panel and windshield are rotated upwards providing room for the wedge to be extended before seat rail tipoff and also providing initial shielding as the crewmember emerges from the cockpit. A sustainer rocket is also provided to ensure clearance of

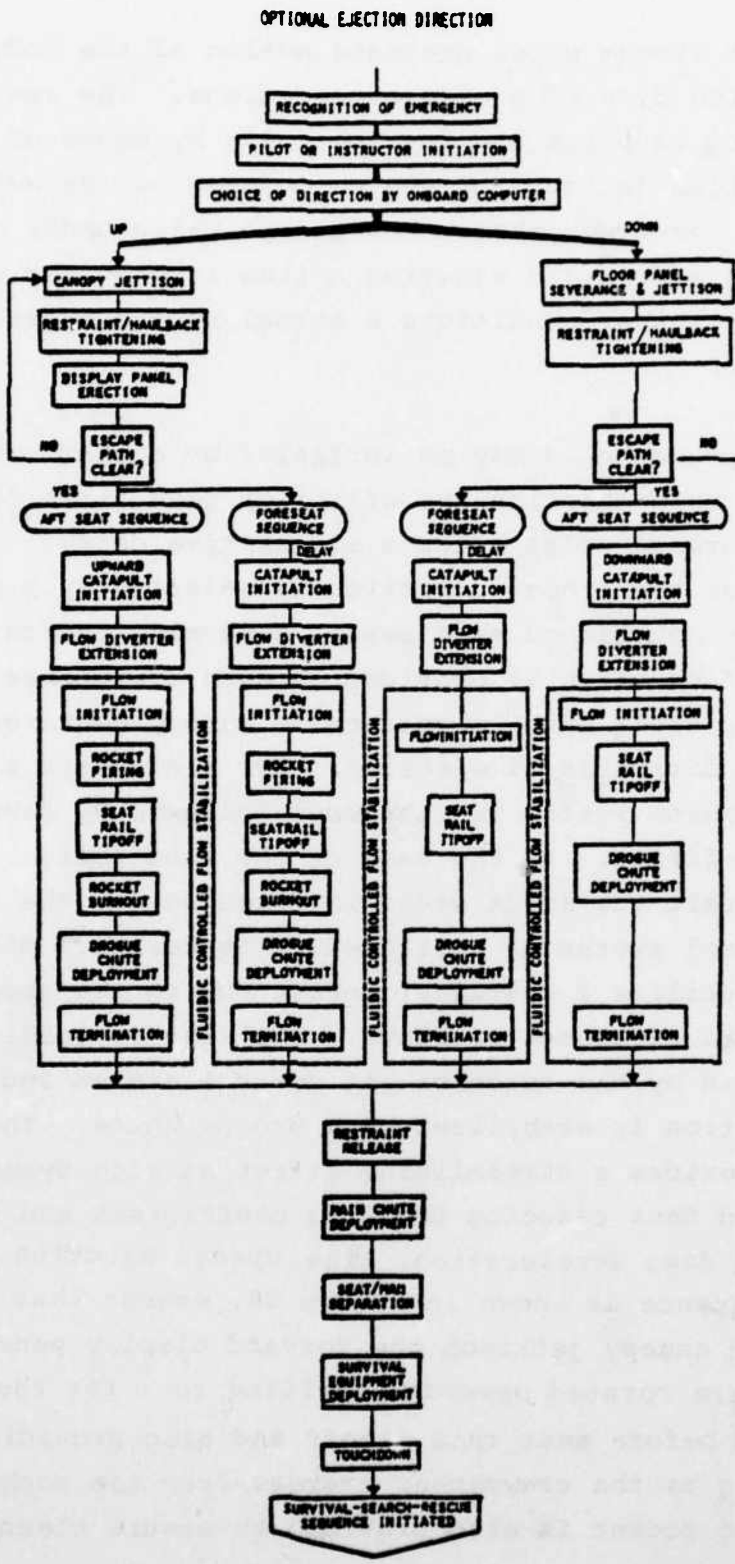


FIGURE 29 OPTIONAL DIRECTION - DEFLECTION WEDGE ESCAPE SEQUENCE

all external aircraft structures during upward ejection.

Several of the design features for this concept are illustrated in the installation drawing, Figure 30. Note the gas storage bottles (for reaction jet controls) may be mounted beneath the seat pan allowing the seat profile to remain relatively narrow. The windshield and upper instrument panel are indicated in the raised position for upward ejection. The lower panel is severed by means of an embedded explosive chord. Once severed the panels are jettisoned by means of individual panel thrusters. The high altitude life support provisions are supplied by means of a new technology pressure suit and an oxygen supply unit.

This concept has many desirable features including positive stabilizing control throughout the escape sequence, ejection capability under any maneuver acceleration, use of a current technology seat, zero-zero escape capability, and high altitude life support through use of a pressure suit. The effectiveness of the reaction jet control system requires further analysis and refinement to verify the control characteristics under dynamic operating conditions. The installation is shown positioned within a 35° seat back angle for structural clearance requirements of the baseline ATS aircraft. The cockpit arrangement can be reconfigured to allow the seat to be positioned with a 50° seat back angle. A supinating seat was not studied; however, it would be possible to utilize such a configuration within the confines of this design by providing a different installation location of the stored gas bottle.

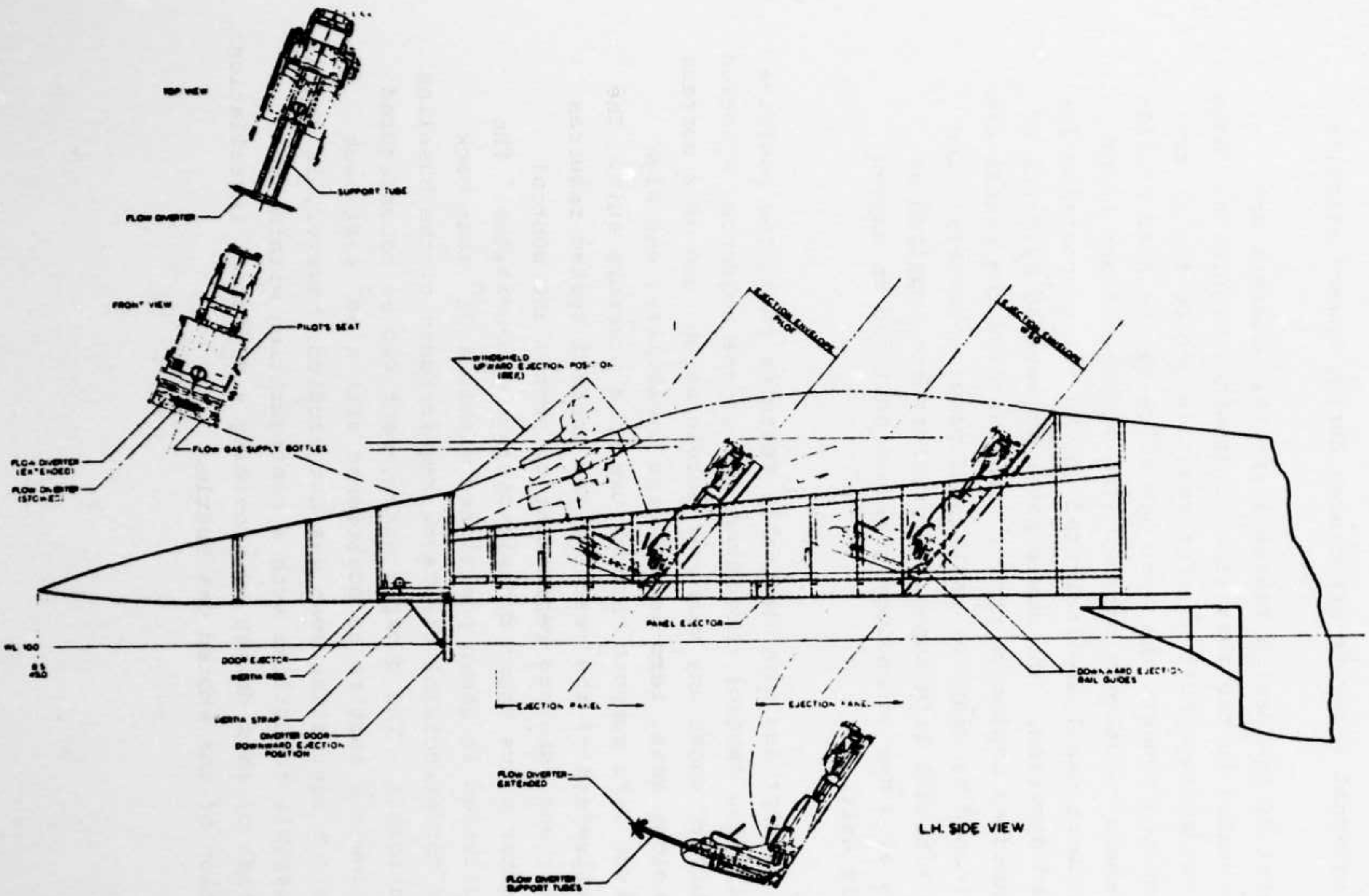


FIGURE 30 OPTIONAL DIRECTION-DEFLECTION WEDGE CONFIGURATION

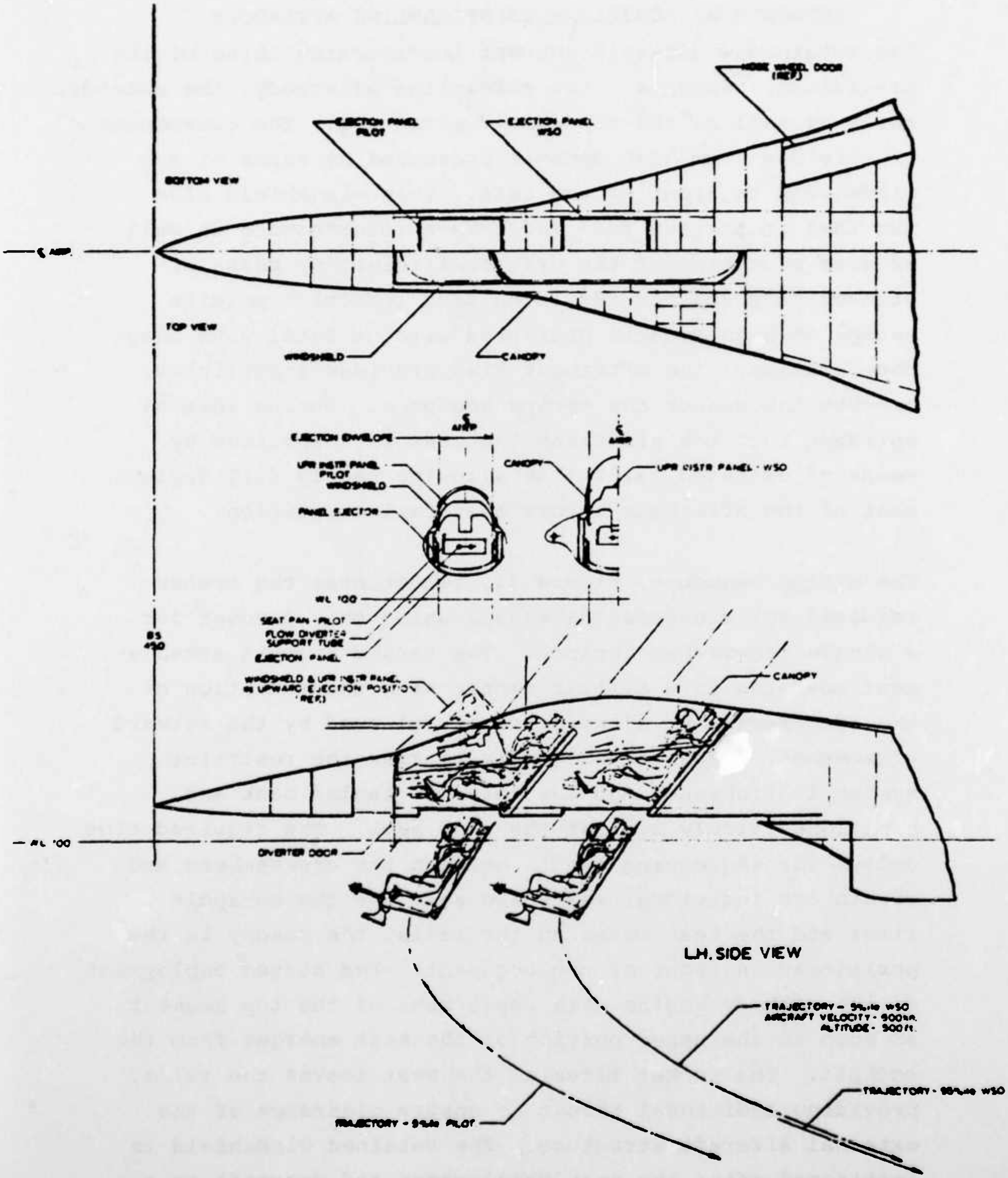


FIGURE 30 OPTIONAL DIRECTION-DEFLECTION WEDGE CONFIGURATION
(CONT'D.)

RETAINED WINDSHIELD WITH STREAMLINE AFTERBODY

The retained windshield concept incorporates three of the preliminary concepts: the streamline afterbody, the extended rails as well as the windshield screening. The crewmember is shielded from high dynamic pressures by means of the windshield in front of the seat. This windshield also provides protection from shock wave interference as well as some reduction of the drag coefficient by means of streamlining and the resulting drag reduction permits escape at high dynamic pressures without fatal wind drag deceleration. The afterbody also provides stabilizing moments throughout the escape sequence. During initial entrance into the airstream the seat is stabilized by means of extended rails thus allowing nearly full deployment of the afterbody before seat-rail separation.

The escape sequence, Figure 31, illustrates the events required for a successful escape using this concept for a single crewmember cockpit. The tandem cockpit arrangement operates in a similar manner with the exception of the aft crewmember ejecting first followed by the forward crewmember. Upon crewmember initiation the restraint system is tightened and the torso is hauled back and positioned firmly against the seat back. The required time delays for sequencing events between the crewmembers and within the individual seats are set. As the catapult fires and the seat moves up the rails, the canopy is repositioned in front of the occupant. The staged deployment of the aftbody begins with deployment of the top segment as soon as the upper portion of the seat emerges from the cockpit. The rocket fires as the seat leaves the rails, providing additional thrust to ensure clearance of the external aircraft structure. The retained windshield is jettisoned after the seat decelerates and descends to a

RETAINED WINDSHIELD WITH STREAMLINE AFTERBODY SEQUENCE

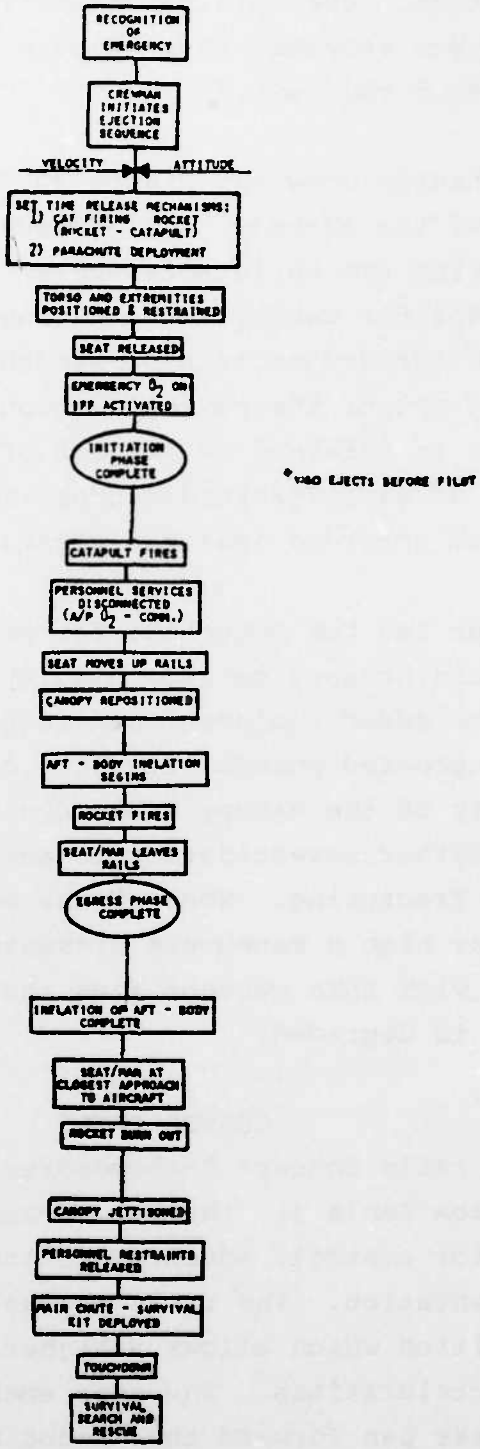


FIGURE 31 RETAINED WINDSHIELD-STREAMLINED AFTERBODY ESCAPE SEQUENCE

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lower altitude. The main parachute is deployed as the restraints are released thus allowing the occupant to be separated from the seat.

The installation drawing, Figure 32, shows the staged inflation of the aftbody, the aftbody pallet for stowing and supporting the inflatable tubes, and the repositioning mechanism for the canopy. The canopy is shown in three pieces, the forward section or windshield is retained by the forward pilot, the center section is jettisoned and the aft section is retained by the aft pilot. A seam along the centerline of each retained canopy allows for separation at this seam prior to seat-man separation.

This concept has the potential for providing excellent stability and protection from high dynamic pressures; however, the added equipment may reduce overall reliability with the increased possibility of a component malfunctioning. The rigidity of the canopy under dynamic conditions also requires further investigation to ensure adequate strength preventing fracturing. None of the methods for providing escape under high g maneuvers presented in Table 4 were compatible with this concept thus the escape under high g's capability is degraded.

CURVED RAILS

The curved rails concept incorporates four of the preliminary concepts from Table 4: the curved rails, movable nozzle thrust vector control, advanced restraint concepts and seat reorientation. The rails themselves guide the seat into a position which allows a higher tolerance to normal maneuver accelerations. The seat emerges from the cockpit with the seat pan forward thus reducing the projected frontal area and also providing shielding from the initial

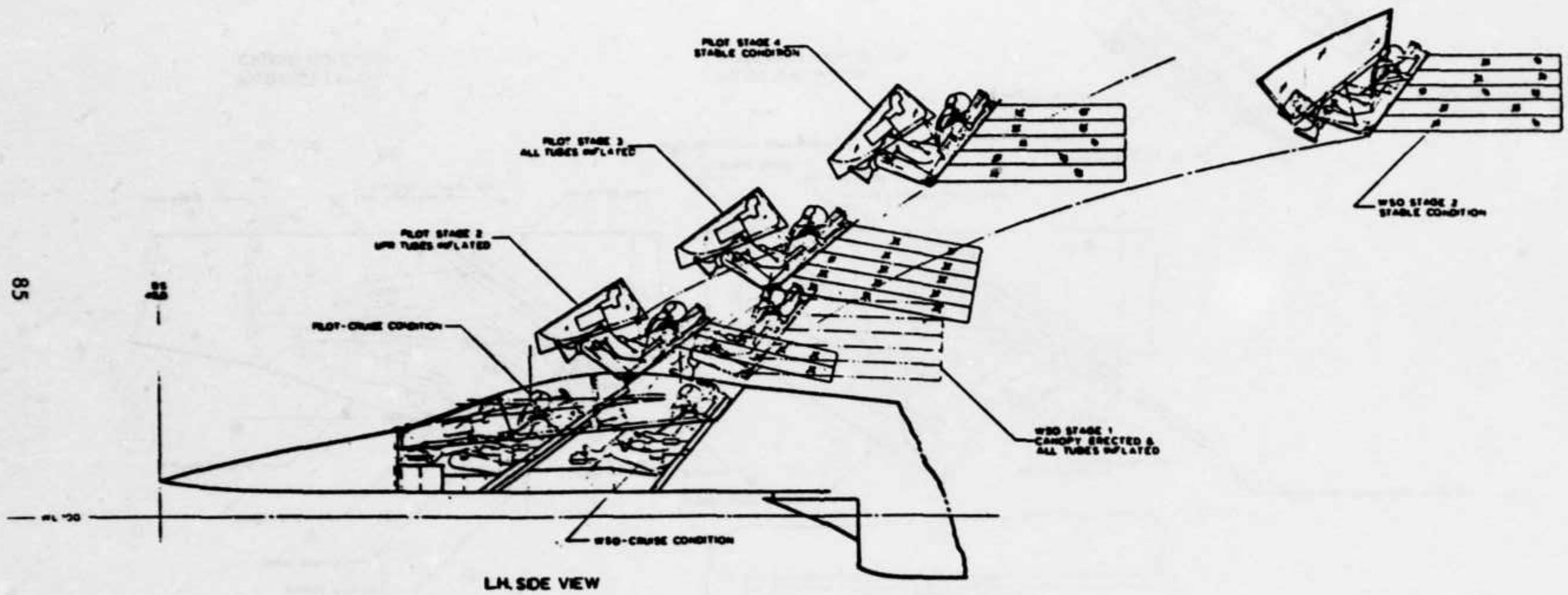

FIGURE 32 RETAINED WINDSHIELD-STREAMLINED AFTERBODY CONFIGURATION

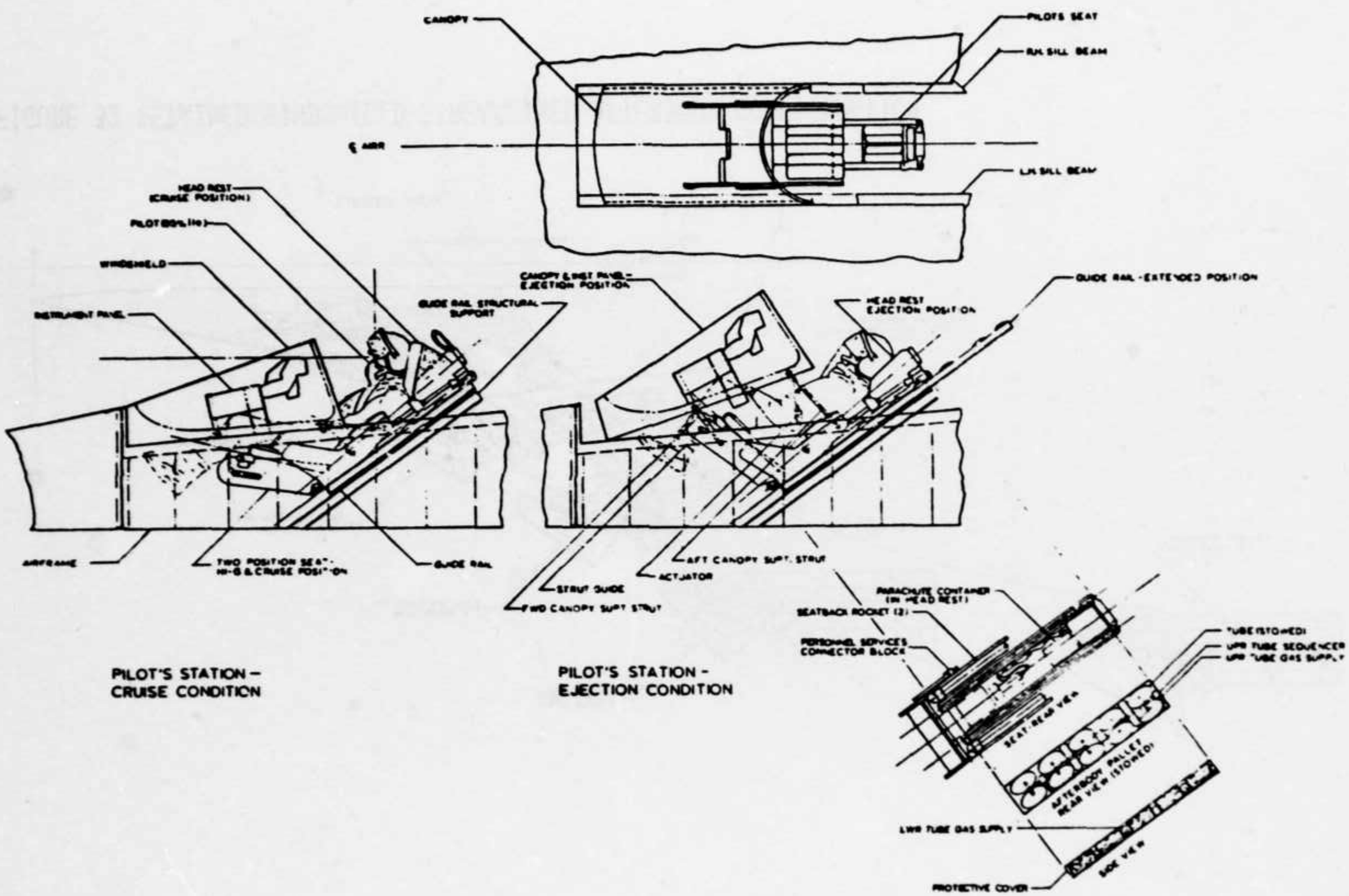

FIGURE 32 RETAINED WINDSHIELD-STREAMLINED AFTERBODY CONFIGURATION (CONT'D)

airflow. The seat is stabilized during the initial phase by means of a thrust vector control system using a movable nozzle. The occupant limbs are secured from flailing by means of an advanced limb and torso restraint system.

As illustrated in Figure 33, the escape sequence may be initiated by either crewmember upon recognition of emergency; however, the aft pilot always is ejected first. The windshield and display panel are raised to provide initial protection from the wind blast. The crewmember limbs and torso are secured to prevent limb flailing and ensure proper spinal positioning for acceptance of accelerations. The catapult fires and accelerates the seat along a curved path. As the seat leaves the rails the rocket fires and the thrust vector control unit becomes effective. The nozzle for the rocket is positioned to allow a thrust vector which is primarily perpendicular to the spine. This produces an effective utilization of the thrust to provide for clearance of external structures on the airplane. A drogue chute is deployed to aid stabilization after the rocket burn is complete. The main parachute is deployed following descent and the occupant is separated from the seat.

The configuration drawing, Figure 34, shows the inherent simplicity of this concept. The windshield is illustrated in the raised position providing a clear path for ejection. The curvature of the rails provide seat reorientation. The forward seat is initially positioned with a seat back angle of 50°, thus requiring a much smaller curvature than the aft seat which is initially at a 35° seat back angle. Detail "A" illustrates the use of a roller truck assembly to permit the seat to move smoothly along the rails. A special catapult pivoting assembly is also

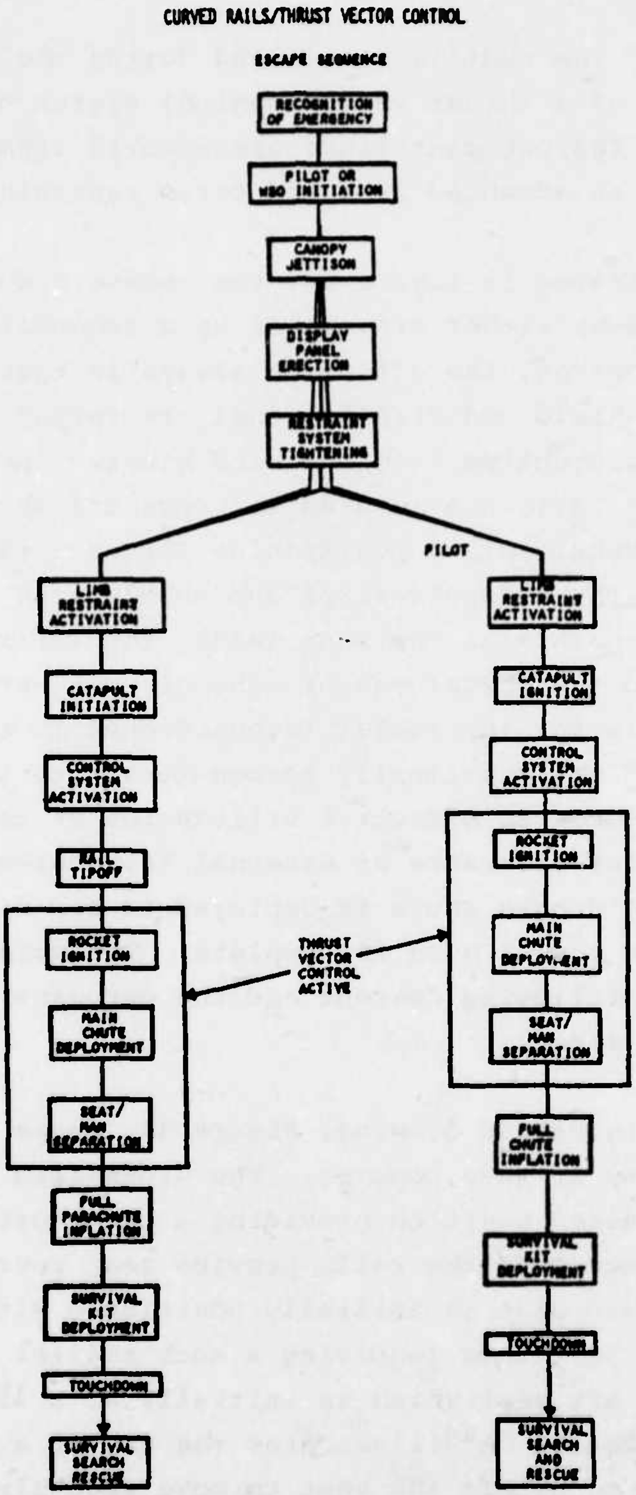

FIGURE 33 CURVED RAILS-VECTORED THRUST ESCAPE SEQUENCE

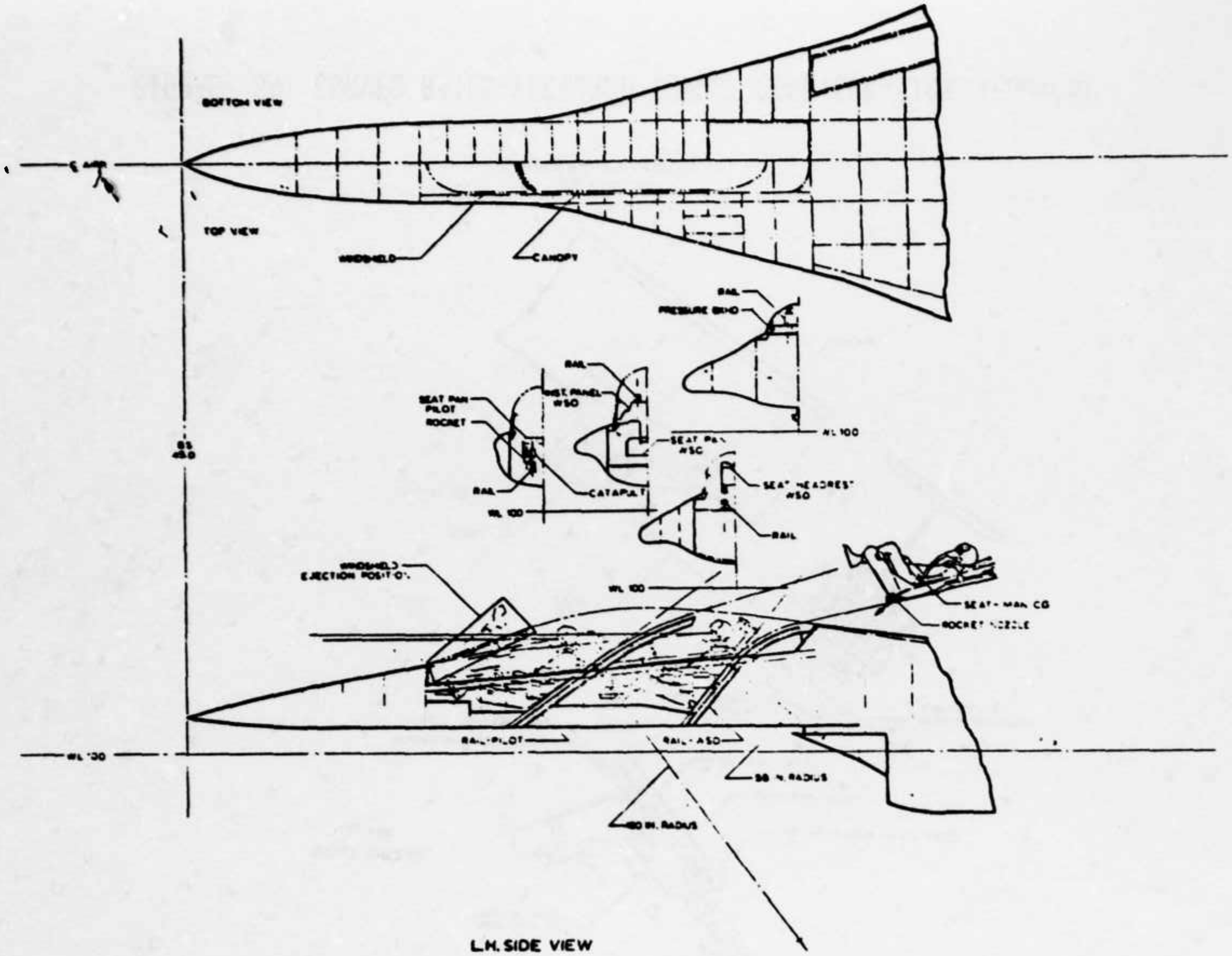

FIGURE 34 CURVED RAILS-VECTORED THRUST CONFIGURATION

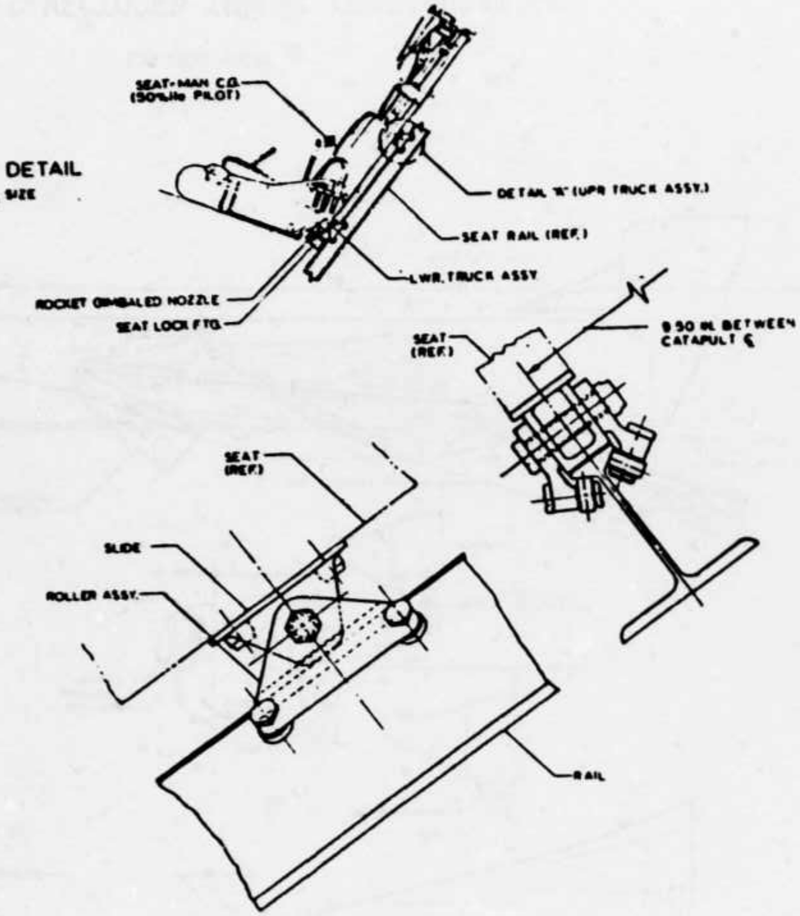

FIGURE 34 CURVED RAILS-VECTORED THRUST CONFIGURATION (CONT'D)

required to allow catapult thrust to be applied while the seat ascends the rails.

The overall effectiveness of this concept is dependent upon the wind drag reduction and associated increase in the maximum dynamic pressure under which the seat may be ejected. This drag reduction must be correlated with the decreased human tolerance to acceleration along the G_z axis in comparison with the G_x axis to determine true benefit from this reorientation. The concept is better suited for use with a supine or semi-supine seat installation as illustrated in the configuration drawing. The tail clearance capability and escape under zero-zero conditions require further analysis to ensure that the low ejection angle is not a hindrance. High altitude life support is provided by an advanced technology pressure suit and oxygen supply unit.

CANOPY CAPSULE

The canopy capsule incorporates three of the preliminary concepts from Table 4: the canopy capsule, movable nozzle thrust vector control, and seat reorientation. In this concept, both pilots escape simultaneously. The canopy provides protection from high dynamic pressure problems through streamlining and shielding of the occupants. If the bottom of the canopy is sealed then the canopy also will provide high altitude life support. This is more feasible for one man crew. The capsule is stabilized by the two movable nozzle thrust vector control units mounted on the seat back which obtain their commands from a microprocessor. Synchronization of propulsion system is critical. Escape while under high acceleration maneuvers is possible due to the seat reorientation prior to escape.

The overall sequence as shown in Figure 35 illustrates the events required for successful escape utilizing this concept. Upon initiation by either pilot, the crewmembers are hauled back and restrained securely against the seat back. The forward display panel is retracted into the nose section to allow pilot rotation into canopy. Both the seats are rotated to give reorientation for the g vector. The capsule is jettisoned and propelled away from the aircraft by means of the synchronized seat rockets. These rockets allow stabilization by means of a central microprocessor which performs the active controlling and sequencing of the essential events. The aft crewmember's drogue chute is deployed first, allowing him to be pulled from under canopy following release of the seat. This is followed by separation of the aft canopy section at the mid cross brace. The forward pilot's drogue chute is then deployed and he is then extracted from under the canopy. Both crewmembers are then recovered following successful main parachute deployment.

Figure 36 presents the installation drawing for the canopy capsule. Of particular note is the absence of a panel closing off the canopy. Within the two man cockpit it was not feasible to enclose the total canopy; however, for a single place cockpit this is feasible. The high altitude life support is provided by pressure suits for each pilot. The seat is rotated by means of an actuator connecting each seat to the canopy frame.

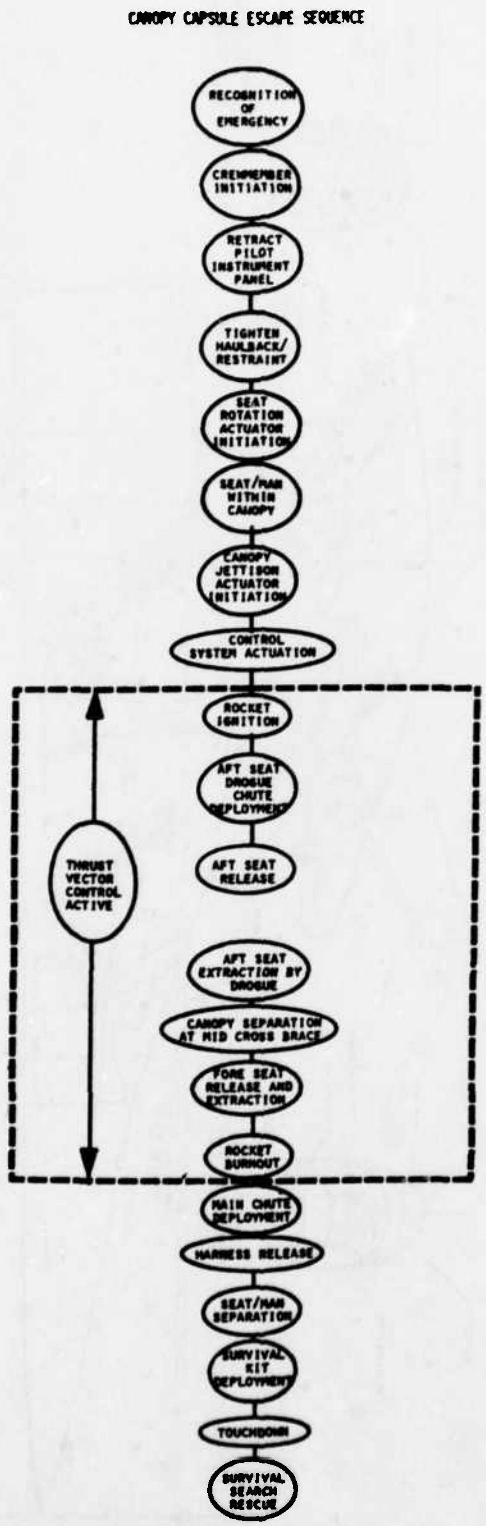

FIGURE 35 CANOPY CAPSULE-VECTORED THRUST ESCAPE SEQUENCE

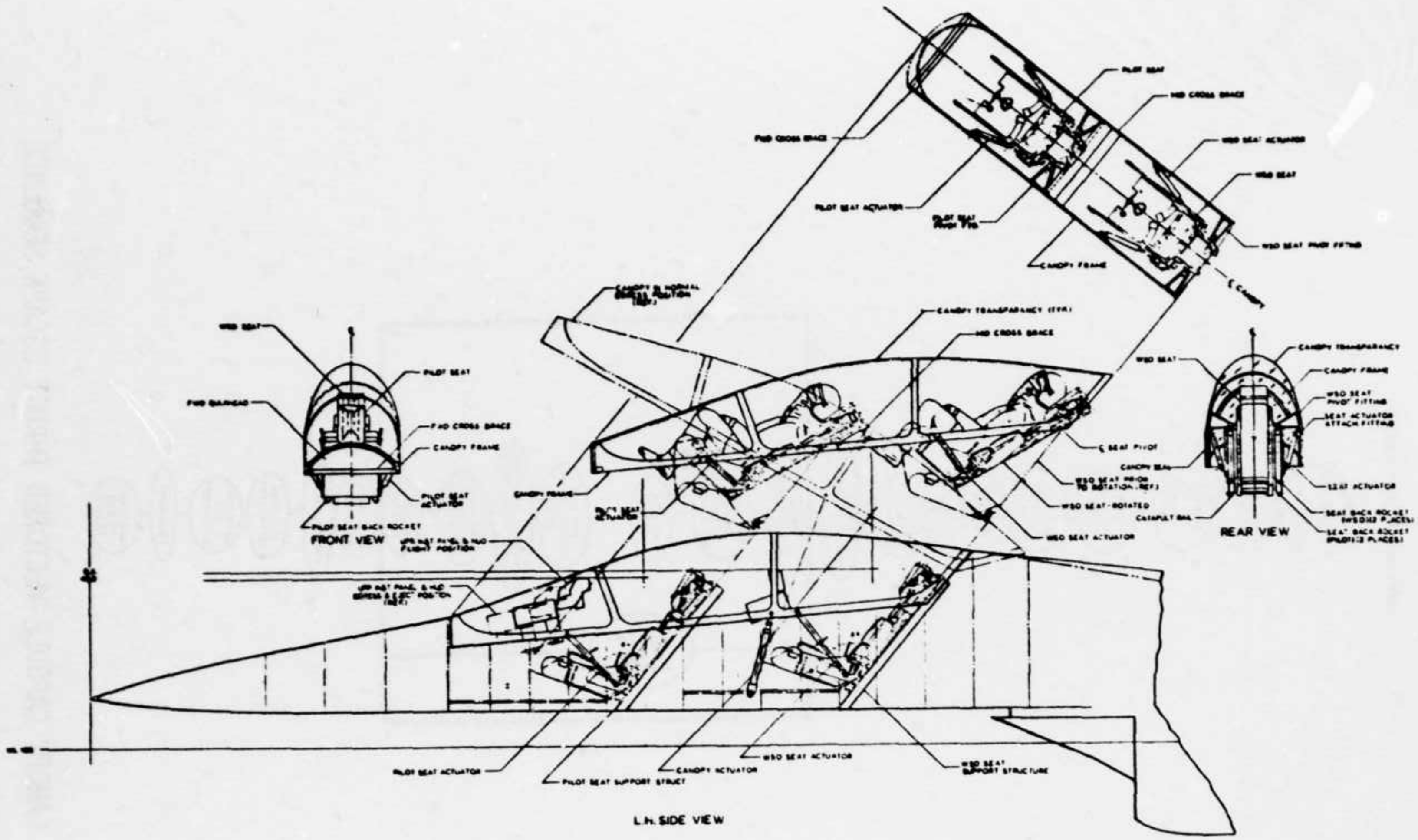

FIGURE 36 CANOPY CAPSULE-VECTORED THRUST CONFIGURATION

SECTION VI
TRADE OFF STUDY

Each of the five concepts were compared utilizing the method described in Section III. The concepts were evaluated in terms of emergency escape capabilities, airframe integration, life cycle cost, development risk, normal crew functions, reliability, maintainability, and impact on search and rescue operations. A description of the results of the comparisons in each of these categories is presented here.

The capability for each concept to provide a survivable escape under a high g maneuver was evaluated using a Boeing three degree of freedom escape system simulation as described in Appendix B. The simulation considered the retained windshield, curved rails and canopy capsule concepts since the downward mode of the optional direction and the forebody separation are both enhanced by higher accelerations. This simulation considered an aircraft maneuvering at Mach 1.3 at 30,000 feet and determined the maximum maneuver loads under which the human tolerance was need exceeded. The retained windshield was estimated to be limited to 8 g's due primarily to the less favorable body position with respect to the maneuver acceleration. Both the canopy capsule and the curved rails concept reorient the crewmember prior to escape to a more favorable body position with respect to the normal acceleration. This resulted in an estimated maximum of 9 g's under which escape could be initiated from the curved rails concept and an estimated maximum of 9 g's for the canopy capsule. The ratings for each concept based upon the results of this study are presented in Table 5.

The high altitude life support is based upon the ability of the concept to provide adequate temperature, pressure and

oxygen for survival at high altitudes. Although a pressure suit may be less comfortable, bulkier, and less efficient than a shirtsleeve environment, it still provides 100% protection up to 80,000 feet. All concepts were therefore rated equally in providing the 100% protection.

The estimated performance of the various concepts in terms of high dynamic pressure is a function of the wind drag deceleration and the provisions for eliminating limb flailing problems. Each of the proposed concepts provides adequate limb flail protection by means of shielding or advanced restraint systems. The escape capability for each of the concepts in terms of wind drag deceleration was also estimated using the Boeing three degree of freedom escape system analysis (Appendix B). This study indicated that all concepts had the potential of providing safe escape at dynamic pressures up to 2000 psf except for the curved rails concept which was limited to 1400 psf due to the reduced human tolerance to deceleration encountered in the seat pan forward orientation. The method and results from an analysis investigating the relationship between seat pitch angle and the maximum dynamic pressure humanly tolerable for the curved rail concept is also presented in Appendix B.

The maximum mach number at which escape may be initiated was estimated to be at least 3.0 for all the concepts due to their shielding or shock wave generating provisions.

The aerodynamic stability of each concept was estimated by the ability of each system to counteract pitching and yawing moments which may be expected during escape system initiation at dynamic pressures up to 2000 psf. The separable forebody was estimated to provide adequate stability due to the stabilizing properties of the retained wing strakes

and also the deployment of the recovery bay access doors to provide additional yaw stabilization. The retained windshield concept is stabilized by means of the streamline afterbody in both the pitch and yaw direction. The optional ejection direction concept is stabilized by means of the reaction jets mounted on the shock producing wedge. Both the canopy capsule and curved rails concept are stabilized through the use of a movable nozzle thrust vector control unit. Preliminary calculations investigating the stability of reaction jet control is presented in Appendix C. All concepts are rated as having the capability to provide a stabilized escape throughout the operating envelope of the aircraft.

The low altitude/adverse attitude capability for each concept was subjectively rated for each concept based upon the ability of the proposed concepts to provide the equivalent low altitude/adverse attitude capabilities as current systems. The separable forebody, curved rails and optional ejection direction concepts were estimated to have at least equivalent capabilities with current systems due to their reliance upon current ejection seats for low altitude. The retained windshield system requires more time to operate due to the necessity of jettisoning the retained windshield prior to successful escape, thus it was rated only 80% as effective at low altitude/adverse attitude conditions. The canopy capsule requires some initial velocity to provide parachute opening during the seat/canopy separation phase. This operation is also time consuming which further degrades low altitude capabilities; therefore, this system was rated ineffective during low altitude and low speed operations. Using the method described in Section III the utility function for each escape performance factor was evaluated and is summarized in Table 5. Each item is considered equally important and thus the average utility for each concept

TABLE 5. SUMMARY OF ESCAPE CAPABILITY

	SEPARABLE FOREBODY	RETAINED WINDSHIELD	CURVED RAILS	CANOPY CAPSULE	OPTIONAL EJECTION DIRECTION
Escape under g	1.0	0.8	0.9	0.9	1.0
High altitude life support	1.0	1.0	1.0	1.0	1.0
High dynamic pressure	1.0	1.0	0.7	1.0	1.0
High mach number	1.0	1.0	1.0	1.0	1.0
Aerodynamic stability	1.0	1.0	1.0	1.0	1.0
Low altitude/ Adverse attitude	1.0	0.8	1.0	0.0	1.0
AVERAGE UTILITY	1.0	1.0	0.9	0.8	1.0

provides the overall value for each concept in terms of the total escape capability.

Airframe integration is rated in terms of weight penalty, volume penalty and integration complexity using the method described in Section III. The weight penalties were determined by means of a weight analysis for each concept as presented in Appendix D. Exact component weight was used where known and other weights were extrapolated from F-15 and F-111 data. Due to the large variations between concepts such as the separable forebody and the optional direction seats, and the different modes of operation of the systems, the weights for each concept were compared on the basis of impact on the OEW of the complete nose section of the aircraft. Hence, given the preliminary nature of the design, the ΔOEW's of the different nose sections came out to be relatively small. The volume penalty was estimated through an approximation of the area dedicated to the escape system including the required swept area within the aircraft for unobstructed ejection. The actual areas which were measured are shaded in the escape system profile views presented in Appendix E. Although area may not be directly proportional to volume, it is a reasonable estimate within the level of system definition.

The integration complexity estimation was based upon the number of interfaces between the escape system and the airframe as tabulated in Appendix F. The ratings resulting from these evaluations are presented in Table 6. Since the weight penalty, volume penalty and integration complexity are considered to be of equal importance, the average of these three ratings is utilized for the overall airframe integration rating.

TABLE 6 SUMMARY OF AIRFRAME INTEGRATION

	SEPARABLE FOREBODY	RETAINED WINDSHIELD	CURVED RAILS	CANOPY CAPSULE	OPTIONAL EJECTION DIRECTION
Weight penalty	1.0	1.0	1.0	1.0	1.0
Volume penalty	.8	1.0	1.0	.8	1.0
Integration complexity	.7	.5	1.0	.9	.7
Average	.8	.8	1.0	.9	.9

The life cycle cost for each concept, based upon the assumptions and method presented in Section III, is presented in Appendix G. The rating resulting from these figures is presented in Table 7.

As previously described, the development risk is based upon the component development status and the overall system development status. The evaluation for the component development status was based upon the individual component status presented in Appendix H. The overall system development status is based upon a subjective rating of each concept. The separable forebody requires significant advances in testing methods to verify the operation of the passive separation technique under a wide variety of operating conditions. This concept also requires the incorporation of two systems: an ejection seat and a stable separable nose section. Taking these two factors into consideration the concept was rated 7 out of 10 in terms of overall development. The canopy capsule requires extensive verification of the integrated thrust vector control system which uses the rockets on each seat. Verification of the capability to extract each crewmember from under the canopy, and detail installation analysis to more accurately define the canopy/seat interface mechanisms and layout is also required. Under these considerations the canopy capsule was rated 6 out of 10 for overall development status. The curved rails, retained windshield and optional ejection direction were each judged to have an overall development status of 8 out of 10 (10 being best) based upon the uncertainties in the performance due to the uniqueness of each concept. The retained windshield requires verification of the stabilization and drag reduction provided by the windshield and afterbody. The optional ejection direction requires verification of the shielding and drag reduction produced by the wedge as well

TABLE 7 SUMMARY OF EVALUATION FACTORS

	SEPARABLE FOREBODY	RETAINED WINDSHIELD	CURVED RAILS	CANOPY CAPSULE	OPTIONAL EJECTION DIRECTION
LIFE CYCLE COST	.79	.91	1.0	.82	.79
Component development status	.74	.6	.69	.75	.59
Overall development risk	.7	.8	.8	.6	.8
AVERAGE DEVELOPMENT RISK	.72	.72	.75	.68	.70
NORMAL CREW FUNCTIONING	1.0	.8	.6	.6	.8
Number of components	1.0	.79	.92	.98	.78
Number of events	.52	.63	1.0	.71	.8
AVERAGE RELIABILITY	.76	.71	.96	.85	.79
Maintainability life	.74	.77	.84	.76	.83
Accessibility	.75	.47	.75	.71	.73
AVERAGE MAINTAINABILITY	.75	.62	.8	.74	.78
SEARCH AND RESCUE	.9	.9	.9	.9	.9

as further evaluation of the effectiveness of the reaction jet stabilization under a wide variety of dynamic conditions. The curved rails requires further definition of the catapult mechanism and also verification of the ability of the seat to travel along a curved rail without malfunctioning. These utility ratings for the overall development status based upon these considerations are presented in Table 7.

Normal crew functioning capabilities were based upon a subjective rating for each concept as described in Section III. The cockpit of the separable forebody provides no reduction in crew comfort, mobility, vision or communication thus resulting in its rating of 10 out of 10. The retained windshield and optional ejection direction concepts both require crewmembers to wear pressure suits which degrade their mobility and comfort thus resulting in a rating of 8 out of 10. In addition to the pressure suit, the curved rails restrict the vision and mobility of the aft crewmember within this concept thus resulting in a rating of 6 out of 10 for this concept. The canopy capsule also requires a pressure suit and in addition the mechanisms connecting the seat to the canopy obstruct the normal motions of both crewmembers thus resulting in a rating of 6 out of 10. The utility function ratings for the category of normal crew functioning are presented in Table 7.

The reliability of the proposed concepts may be predicted by the number of components in each concept and also by the number of essential events required by each concept. A component equipment list for each concept was prepared for each concept and the total number of components estimated from this list. These lists are presented in Appendix I.

The number of essential events required to produce a successful escape was determined by summing the events which are illustrated in the operational sequence charts of Section V. The utility ratings resulting from these evaluations are presented in Table 7.

The maintainability is a function of the average operational life and also the accessibility of components for maintenance. The operational life of each component was estimated and presented in Appendix J. The average operational life was estimated by summing the product of the number of components and their respective lives and dividing this sum by the total number of components. The accessibility of each component was then estimated through an examination of the installation drawings, with the results of this examination being presented in Appendix K. The utility ratings from both these evaluations are presented in Table 7.

The ability for each new concept to provide proper survival and locating equipment to ensure safe crewmember recovery and rescue were rated equivalent. This subjective rating is due to the fact that no particular enhancements or deletions were incorporated within the individual concept designs thus making them essentially equivalent to current systems. However, current systems provide several inadequacies in terms of crewmember locating and survival equipment thus resulting in a search and rescue rating of 9 out of 10 for all concepts.

The overall results of the trade off study are summarized in Table 8.

These trade off study results indicate a relatively close desirability for all five concepts. The three concepts

TABLE 8. OVERALL EVALUATION

	FIGURE OF MERIT	SEPARABLE FOREBODY	RETAINED WINDSHIELD	CURVED RAILS	CANOPY CAPSULE	OPTIONAL EJECTION DIRECTION
Emergency Escape Capability	.25	1.0	.9	.9	.8	1.0
Aircraft Integration	.16	.8	.8	1.0	.9	.9
Life Cycle Cost	.16	.8	.9	1.0	.8	.8
Development Risk	.06	.7	.7	.8	.7	.7
Impact on Normal Crew Functioning	.16	1.0	.8	.6	.6	.8
Reliability	.09	.8	.7	.9	.8	.8
Maintainability	.09	.8	.6	.8	.7	.8
Survival and Rescue	.06	.9	.9	.9	.9	.9
OVERALL EVALUATION		.9	.8	.9	.8	.9

grouped into a higher rating were the separable forebody, the optional ejection direction, and the curved rails. Of these three concepts the separable forebody and the optional ejection direction provide potential for total escape capabilities throughout the operating envelope. However, due to the high level of aircraft integration required for the separable forebody, it did not rate as well within such categories as cost, development risk and aircraft integration. The optional ejection direction system requires the development, testing and incorporation of two new concepts, the reaction jet control system and the two directional escape. Because of the additional equipment and the uniqueness of the design this concept rated lower in terms of items such as cost and aircraft installation. The curved rails concept did not have the high level of performance improvement in terms of g capability as found within the other two concepts; however, due to the relative simplicity of this concept, it rated well in terms of cost, development risk, reliability and aircraft integration.

The two concepts which were rated slightly lower than the above three are the retained windshield and the canopy capsule. The retained windshield concept provides the potential for full protection throughout the escape envelope. The incorporation of two new concepts (the windshield attachment and the streamline afterbody) requires that a relatively greater level of development than the other concepts, which resulted in lower reliability, maintainability and development risk estimates. Further development and analysis of these two subsystems could lead to improved ratings in these categories for the overall concept. Upon examination of the canopy capsule within the context of a two man cockpit the escape capability performance estimates

were not as high as initially anticipated. Utilizing this concept in conjunction with a single place cockpit may substantially improve the overall rating.

OVERALL SUBJECTIVE RATING

A color coding scheme categorizing the most promising concepts was prepared. No systems were coded green, ready to go, since all concepts incorporate new technology items and associated uncertainty. The separable forebody, optional ejection direction and retained windshield concepts were coded blue, high potential. The canopy capsule concept and curved rails concept were coded amber, lower potential.

The separable forebody has a high potential for success due to its similarity to both the capsule and ejection systems. The development of a passive separation technique and escape mode sequencing requires further study and is highly configuration sensitive, thus creating uncertainty in the ultimate performance of the system. The optional ejection direction provides potential for improved escape capabilities under high g situations, crewmember shielding from high mach numbers and high dynamic pressure, and stabilization through reaction jet control. Each of these new components have associated uncertainty with their usage in a crew escape system. The retained windshield brings two new elements to crew escape. The use of afterbody streamlining and stabilization provides a means of controlling the ejection seat throughout the escape sequence. The use of the windshield as a screening element provides limb flail protection at high dynamic pressure. Both devices are developed and thus the problem is that of integrating them into a common system.

The canopy capsule does not provide the high altitude protection initially envisioned due to the inability to totally seal off the compartment when integrating this concept into a two man tandem cockpit. The proposed shirt-sleeve environment for this system initially made it attractive, thus loss of this advantage makes this concept less attractive. Additional problems arise involving the dual rocket synchronization. The curved rails concept was configured under the assumption that the reduced projected area of the seat pan and ensuing drag reduction would result in an increase in the dynamic pressure capability under which the ejection could be initiated. While this reorientation reduces the overall aerodynamic drag a greater reduction in tolerance to deceleration along the $\pm G_z$ axis degrades the high dynamic pressure performance which is unacceptable.

ADDITIONAL DETAIL - SELECTED CONCEPTS

The numerical rating technique identified the separable forebody, the curved rails and the optional ejection direction concepts as providing better overall capability. The subjective rating identified the separable forebody, the retained windshield, and optional direction concepts as having better potential for providing the desired improvements in escape capability. Based upon these two rating systems the separable forebody concept, retained windshield concept, and optional ejection direction concept were selected for further refinement. Analysis was performed on the separable forebody and the optional ejection direction to refine the stability predictions.

Calculations considering the separable forebody at small angles of attack were performed to estimate the static longitudinal and directional center of pressure locations. These calculations were performed for the flight mach

number range from 0.6 to 3.0 based on the methods and data of the USAF stability and control DATCOM (Reference 3). The center of pressure locations for this speed range are presented in Figure 37. The static stability for this concept may be enhanced by modification of the basic configuration. The revised center of pressure locations for this improved model are also presented.

The separable forebody configuration concept as given in Figure 28 was considered for the estimates of lift curve slope and pitching moment curve slope that gave the c.p. location. The wing was taken as a plane surface and lift curve estimates were made without consideration of leading edge vortex separation that can occur on such a slender wing configuration. Furthermore, no consideration was given to possible base drag contribution to static stability, both longitudinal and directional. As part of the static directional stabilization it was considered that the two access doors to the separation and recovery bay were in the extended (open) position. The estimates show that the flight vehicle with c.g. at BS 225.1 is longitudinally unstable at flight mach numbers greater than 2.3, but is directionally stable throughout the speed range.

Because of the deficiency in longitudinal stability, an alternate configuration was considered with the break occuring at BS 336.8 running up from the lower surface to a fore and aft-lateral split in the plane of the gun tube to connect with the original break section of the crew compartment. This would give a continuous wing leading edge and a bottom surface such that the projected wing plan area is increased to 71.5 ft^2 from 50.2 ft^2.

Also included in the configuration for directional stability

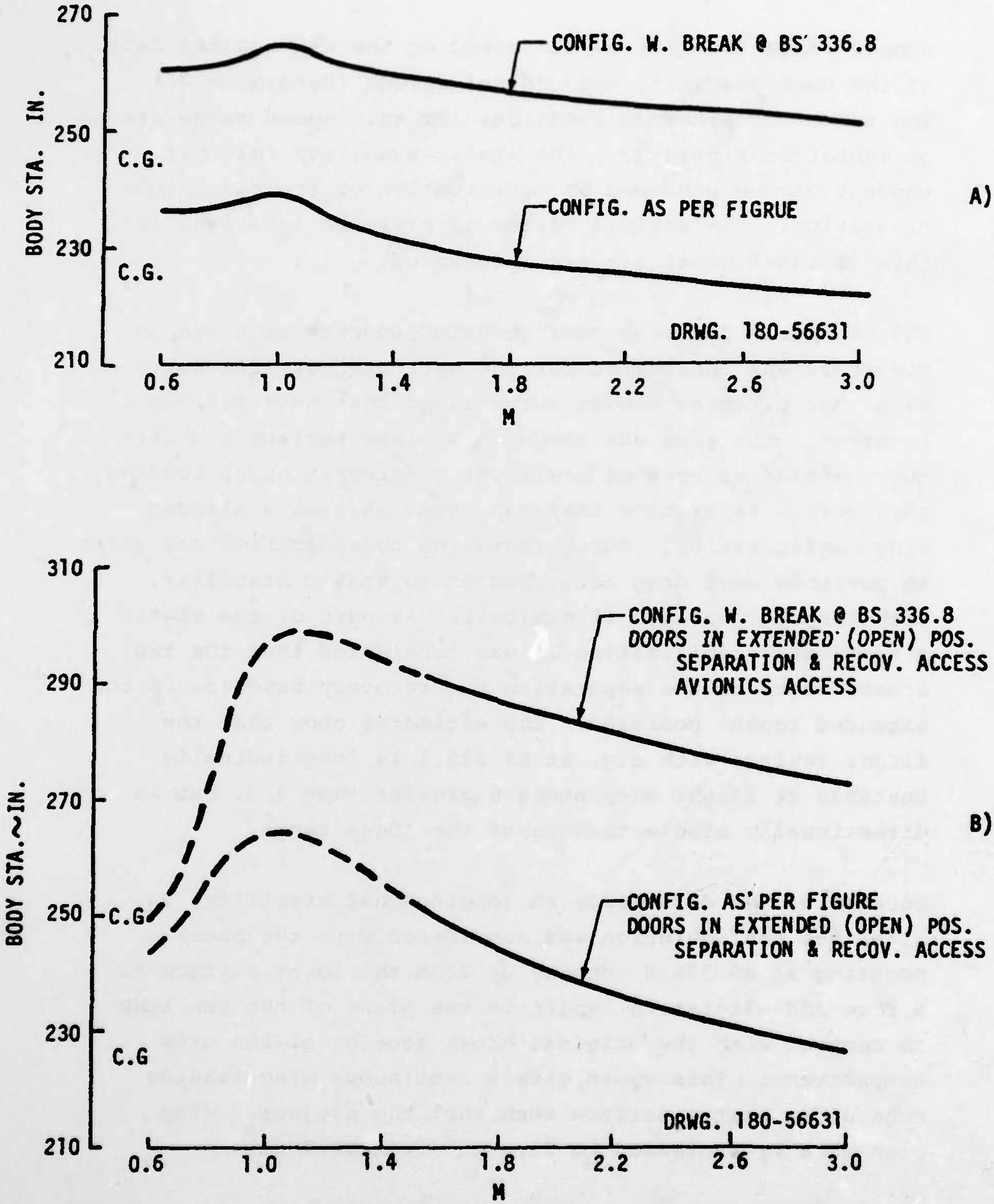

FIGURE 37 STATIC CENTER OF PRESSURE ESTIMATES FOR SEPARABLE FOREBODY OF MODEL 987-230B A) LONGITUDINAL B) DIRECTIONAL

estimates were the two avionics access doors (shown in phantom on the drawing) in the extended (open) position. These doors were assumed, for the static stability estimates, to form continuous surfaces (flat plates) with the doors of the original configuration noted above. The results of c.p. location estimates show a significant shift aft, except for the directional c.p. at the one subsonic mach number (M=0.6) where the estimate was made. Here, the contribution of the additional door area to side force coefficient slope was greatly affected by the reduction in effective "vertical tail" aspect ratio.

Since the crew escape compartment is to be capable of separation while maneuvering at mach 3 where the static directional stability is reduced, it would appear that the present configuration of a fighter forebody with highly-swept wing surface should be investigated as to susceptability of induced roll due to sideslip.

Further design refinements for the optional ejection direction concept led to a preliminary estimate of the stored gas requirements for the reaction jet stabilization system and also a preliminary pneumatic circuit definition incorporating the fluidic control unit for the jets. The storage requirements for the reaction jet control system were based upon utilizing this system during the initial 0.85 seconds of the escape sequence. If the escape was initiated at an initial dynamic pressure of 2000 psf then it was estimated that following the 0.85 second the ejection seat would decelerate to a dynamic pressure condition under which parachute deployment and stabilization is possible. Details of these calculations and assumptions are presented in Appendix C. These estimates indicated a requirement for 20-25 pounds of compressed nitrogen gas at 3000 psi.

The preliminary pneumatic system configuration for the reaction jet control of the optional direction concept was developed to provide the capability to perform separate functions. First the pneumatic system extends the diverter wedge to its fully deployed position. Then the gas is utilized to sense changes in angular rates by means of fluidic rate sensors. The system finally supplies fluid to the reaction jets to control and stabilize the ejection seat.

These functions are provided by the pneumatic components illustrated in Figure 38. The system consists of a power source, a supply tank, a bypass circuit for extension of the wedge, a pneumatic rate sensor package, an output power amplifier, and individual plumbing to provide power to the upper or lower control nozzle.

The power supply package consists of a dual source high pressure gas. The individual bottles are interconnected by a selector valve. The high pressure gas is collected in the plenum (supply tank). During the extension phase the gas is vented to the extension tubes by way of the bypass circuit. This assures that the extension process will be quick and reliable. The two stage extension consists of initial extension forward from the seat followed by the sidewards extension of the wedge. Following the full extension, the bypass circuit is shut and the flow is directed through the control circuit. A fluidic rate sensor is utilized to determine angular rates. The signal from the rate sensor is amplified and utilized to determine the magnitude of the flow which will be supplied to the upward or downward pointing nozzles.

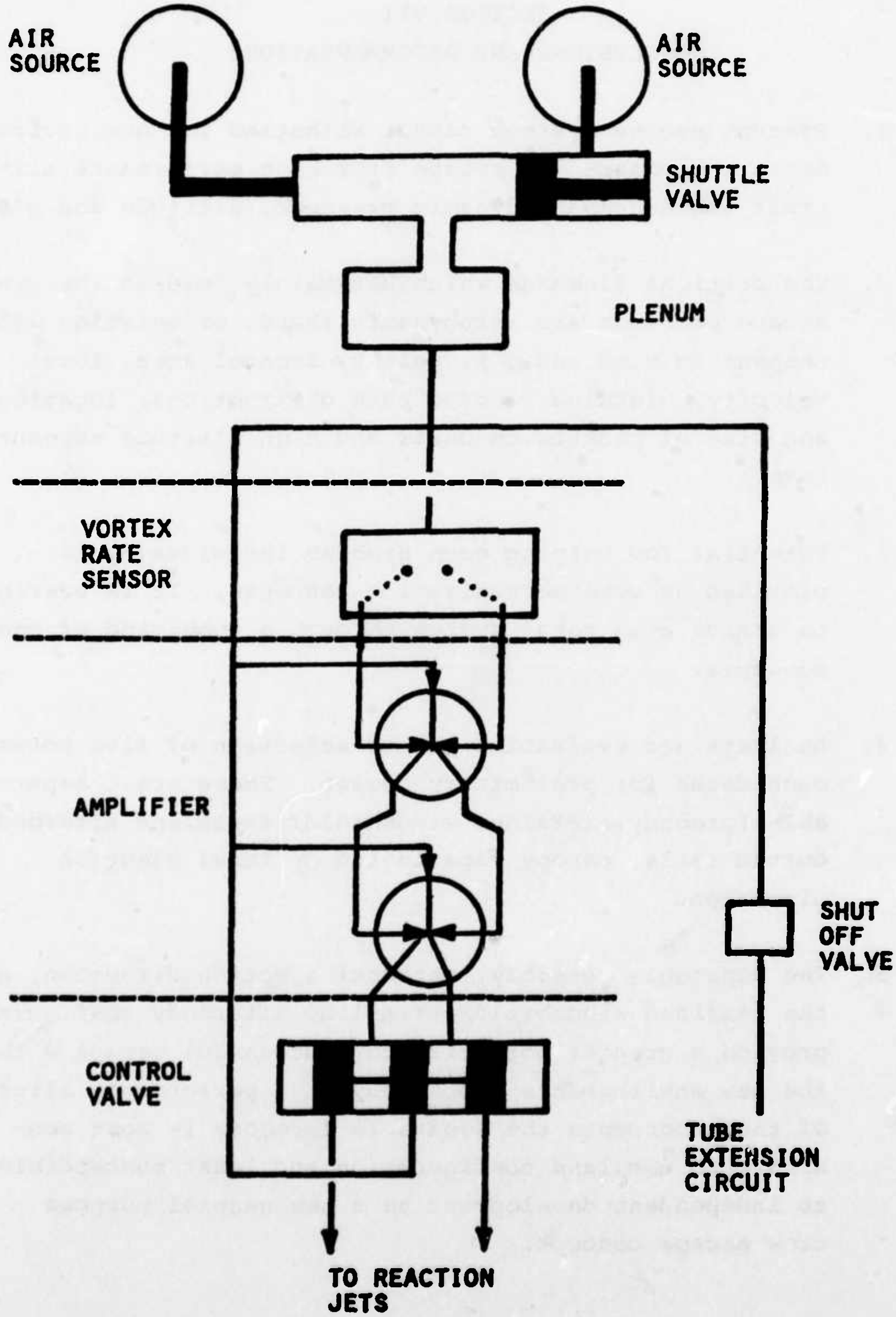

FIGURE 38 PNEUMATIC CIRCUIT DIAGRAM FOR REACTION JET CONTROL UNIT

SECTION VII
CONCLUSIONS AND RECOMMENDATIONS

1. Present escape systems cannot withstand the new environments encountered in escape from high performance aircraft (mach number, dynamic pressure, altitude and g's).

2. The critical elements which ultimately lead to the crew escape problems are aerodynamic shape, orientation with respect to wind and g's, weight, frontal area, local velocity, clothing, escape path obstructions, location and size of propulsion units and high altitude exposure time.

3. Potential for solving each problem individually is provided by some mechanization concepts. It is possible to arrive at a total system through a combining of these concepts.

4. Analysis and evaluation led to selection of five potential candidates for preliminary design. These are: separable forebody, retained windshield/streamline afterbody, curved rails, canopy capsule and optional ejection direction.

5. The separable forebody, optional ejection direction, and the retained windshield/streamline afterbody configurations provide a greater potential for successful escape within the new environments imposed by high performance aircraft. Of these concepts the separable forebody is most sensitive to airplane configuration and least susceptible to independent development as a new general purpose crew escape concept.

6. As a minimum it is recommended that three of the five preferred concepts (separable forebody, retained windshield/streamline afterbody, optional ejection direction) be studied in greater detail to fully understand their performance capabilities under all operating and service conditions.

APPENDIX

A. Human Tolerance Data

B. Escape System Simulations Under High G and High Dynamic Pressure Situations

C. Feasibility of Reaction Jet Stabilization

D. Concept Weight Estimations

E. Concept Volume Estimations

F. Concept Interfaces

G. Concept Life Cycle Cost Estimations

H. Concept Component Development Status

I. Concept Component Equipment Lists

J. Concept Operational Life Estimations

K. Accessibility of Components

APPENDIX A

HUMAN TOLERANCE DATA

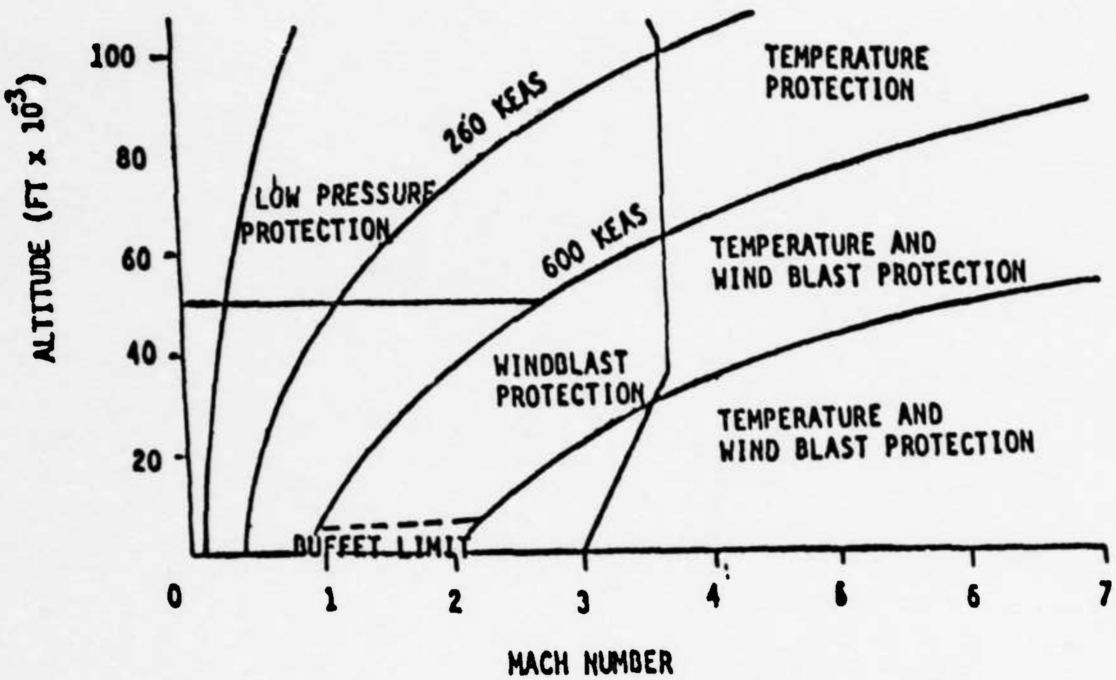

FIGURE A-1 PRESSURE, TEMPERATURE, AND WINDBLAST PROTECTION REQUIREMENTS

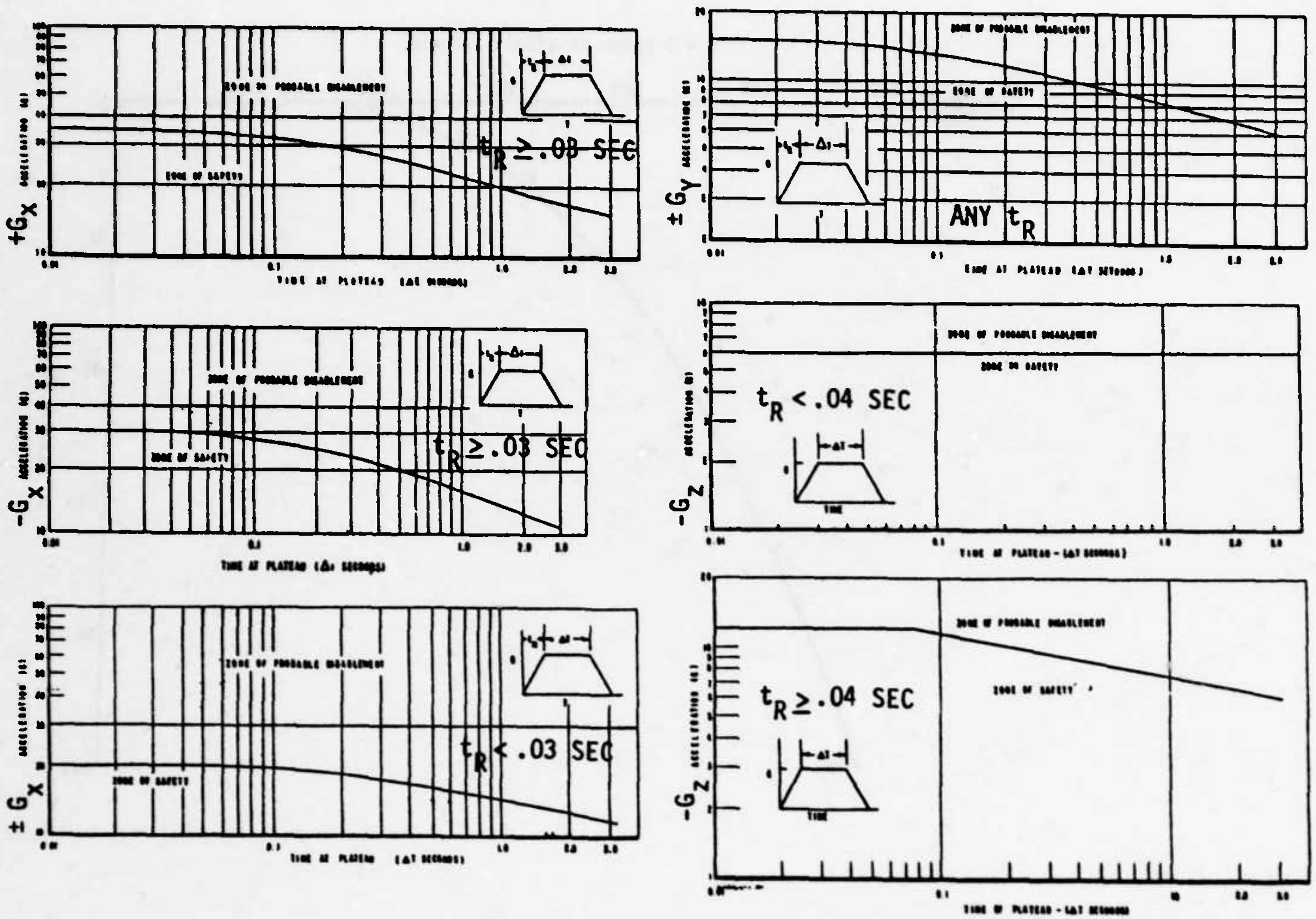

FIGURE A-2 HUMAN ACCELERATION TOLERANCES (FROM REF. 4)

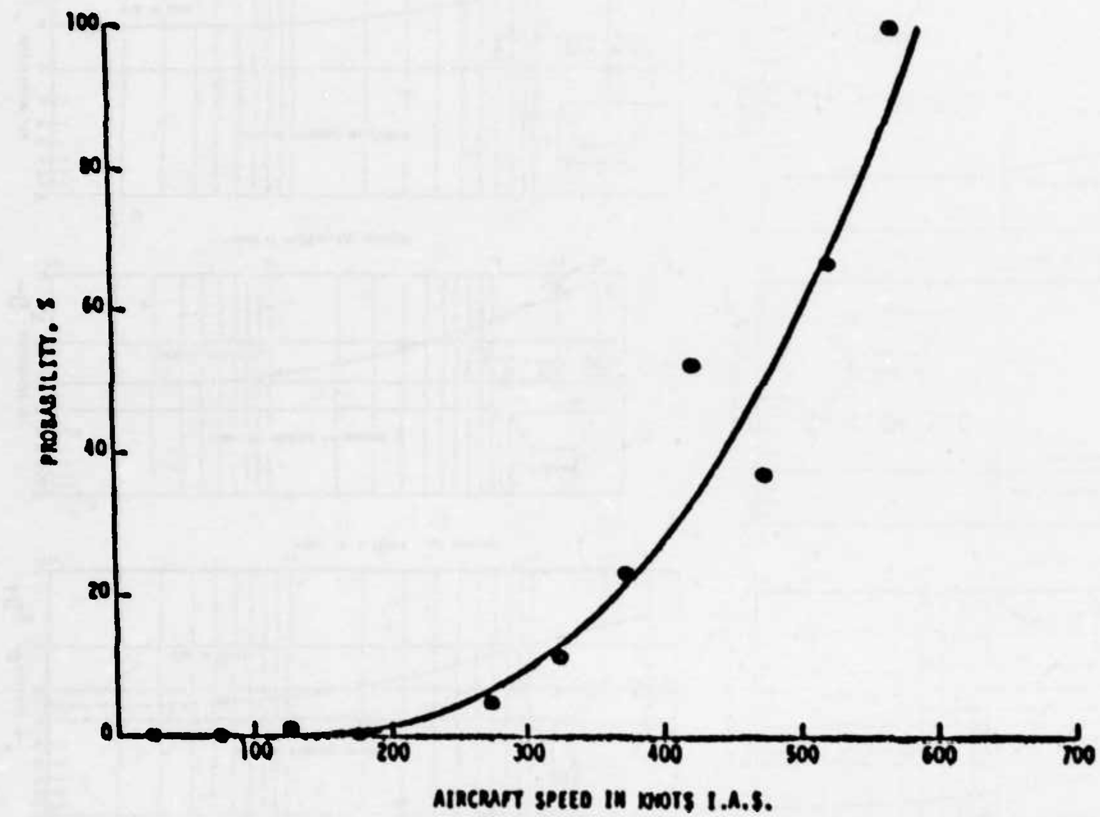

FIGURE A-3 PROBABILITY OF FLAIL OR POSSIBLE FLAIL INJURY AT A GIVEN EJECTION SPEED (USAF AIRCRAFT: 1957-1970)

APPENDIX B

Escape from an aircraft under high g or high dynamic pressure conditions is based upon the ability for the stabilized ejected mass to clear the external aircraft structure while staying within human limits of acceleration. The acceleration, and therefore the escape trajectory, is a function of the forces acting on the seat (catapult, rocket and aerodynamic). The human tolerance to acceleration is based upon the resolution of the total acceleration into its components along the various body axes. As provided in Mil S-9479B (Reference 4) the human tolerance is limited by the following equation:

$$1 \leq \left[\left(\frac{G_X}{G_{XL}} \right)^2 + \left(\frac{G_Y}{G_{YL}} \right)^2 + \left(\frac{G_Z}{G_{ZL}} \right)^2 \right]^{1/2}$$

where G_{ZL}, G_{XL}, and G_{YL} are acceleration limits for their respective axis and G_X, G_Y, and G_Z are the acceleration components along the body axes.

A Boeing time history simulation, ESCAPE, was utilized to evaluate the structural clearance and the accelerations along the human body axes for selected concepts under critical operating conditions.

The computer program utilizes a three degree of freedom simulation considering longitudinal and vertical displacement, and rotation about the lateral axis (pitch). The forces and moments acting on the ejected system are summed at discrete time intervals and this sum is divided by the mass to obtain the accelerations. A fourth order Runge-Kutta integration scheme is utilized to obtain velocities and positions from these accelerations.

This procedure results in the establishment of a time history of the escape sequence from the time of initiation to the time of clearance of all aircraft structures. The Boeing ATS Model 987-230B (Figure 3) was used as the structure from which the crewmembers escaped.

Dynamic pressures up to 2000 psf were simulated by consideration of an aircraft flying 1300 ft/sec at sea level. Using the dimensions, streamline factors, mass, and applied forces listed in Table B-1, each concept was tested at dynamic pressure conditions of 2000 psf. The streamline factors were based upon drag reduction estimates for streamline afterbodies and forebodies from Hoerner (Reference 7). Those concepts which didn't meet the 2000 psf requirement were re-analyzed by decrementing the velocity until a safe ejection within human acceleration tolerances was attained. All concepts except the curved rails concept met the 2000 psf requirement. The curved rails concept was shown to have the capability of withstanding a dynamic pressure of 1400 psf.

This degradation in high dynamic pressure capability for the curved rails/seat pan forward concept was investigated further. The reduction in drag associated with rotation of the seat toward a seat pan forward orientation was correlated with the reduction in deceleration tolerance along the G_z axis in comparison to the G_x axis.

The analysis considers a typical high technology ejection seat (ACES-II) which is subjected to a high dynamic pressure environment equalling the human tolerance. The seat is studied using pitch angles of attack from 0°-180° while fixing roll and yaw angles at zero. The force coefficients are obtained from AFFDL-TR-74-57 (Reference 5) using rocket off conditions at mach 0.9. The results from this analysis,

TABLE B-1 ESCAPE SYSTEM SIMULATION SUMMARY

	OPTIONAL EJECTION DIRECTION	WINDSCREEN	CAPSULE	CURVED RAILS
REF. AREA (Ft^2)	7	10	10	7
STREAMLINE SHAPE FACTOR	.6	.4	.4	1
EJECTED WEIGHT (Lbs)	450	600	1,150	400
CATAPULT FORCE (Lbs)	5,500	8,000	15,000	5,500
ROCKET FORCE (Lbs)	4,800	7,000	14,000	4,800
MAX DYNAMIC PRESSURE (psf)*	2,000	2,000	2,000	1,400
MAX LOAD FACTOR	Not Applicable	9	9	8

* ESTABLISHED DURING STRAIGHT AND LEVEL FLIGHT.

as shown in Figure B-1, indicate approximately a thirty percent reduction in the maximum dynamic pressure for a seat oriented with the seat pan forward. This agrees with the results obtained from time history simulation.

The time history simulation, ESCAPE, is also utilized to assess the maximum load factor under which a safe escape could be initiated. Since neither the optional ejection direction nor the separable forebody concepts utilize an upward ejection under high g conditions, only the curved rails, canopy capsule, and retained windshield concepts were considered. Escape within a high acceleration maneuver requires the ejection platform to attain sufficient velocity with respect to the airplane to ensure clearance of all aircraft structures. The airplane was considered to be operating at mach 1.3 at an altitude of 30,000 feet. The airplane was considered to be maneuvering under a load factor of 10 g's. If a safe escape could not be performed at this load factor then the airplane load factor was decremented until a safe escape could be accomplished. The results of this study are listed in Table 3. Both the canopy capsule and curved rails concept reorient the body prior to leaving the airplane allowing the application of a larger rocket force perpendicular to the human spine. Due to the ability to add this force these two concepts perform better under high g maneuvering conditions.

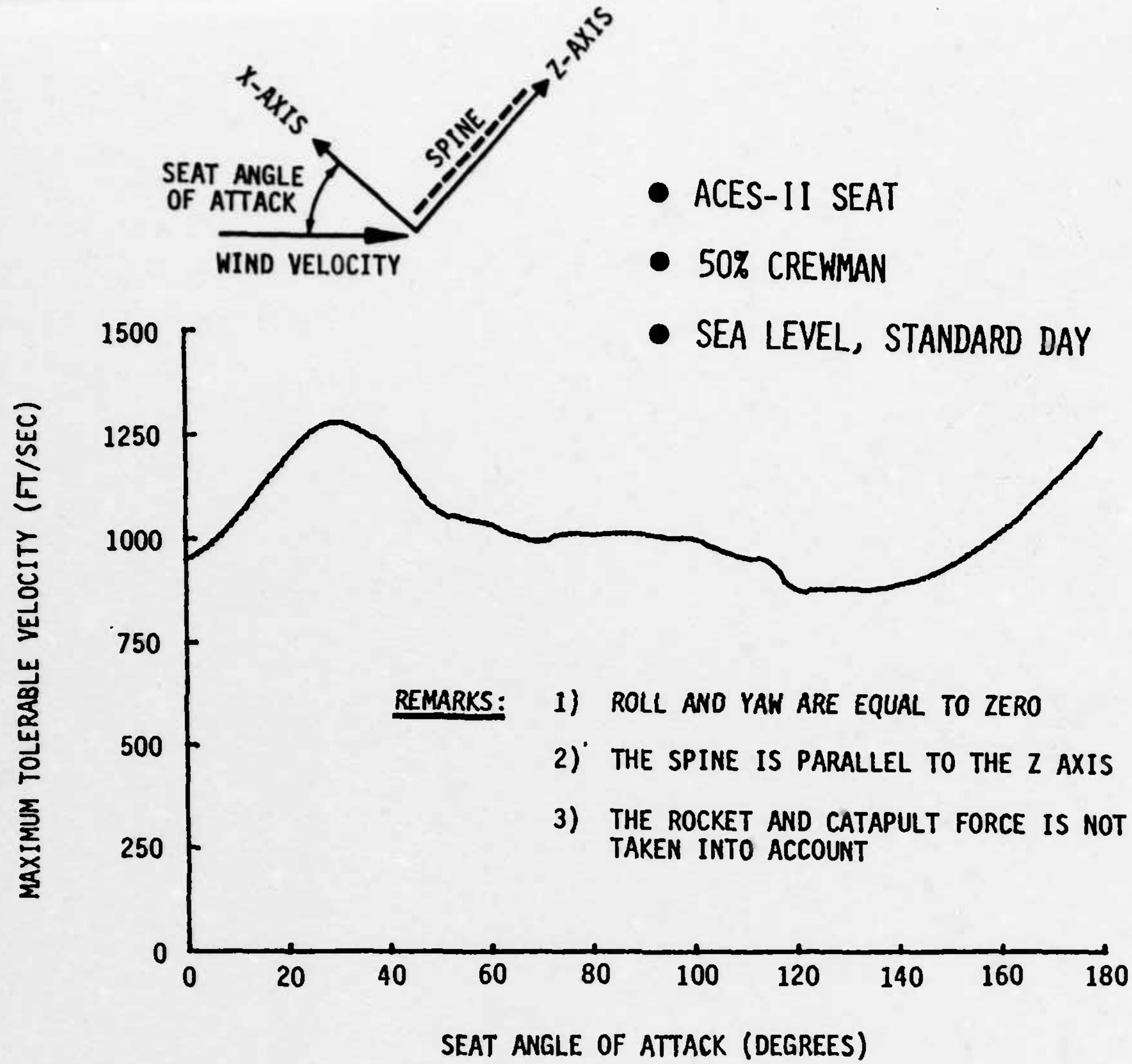

FIGURE B-1 MAXIMUM TOLERABLE WIND VELOCITY AS A FUNCTION OF SEAT ORIENTATION

APPENDIX C

FEASIBILITY OF REACTION JET STABILIZATION

One method of stabilizing ejection seats is provided by using a reaction jet control unit. The feasibility of using this concept is based upon its capability to counteract upsetting moments which may occur at operations within a dynamic pressure environment up to 2000 psf and also being physically sized so that it fits within the confines of the seat.

ESTIMATION OF CONTROL REQUIREMENTS

Both pitch and yaw moments are critical to the stability of the seat. Since pitching moments for an ejection seat are greater than yawing moments, the various concepts will be sized by considering their ability to counteract pitching moments only. The aerodynamic characteristics of the ejection seat are obtained from AFFDL-TR-74-57 (Reference 5) considering an ACES II ejection seat with pitch angles from -90° to $+90^{\circ}$. The maximum pitching moment coefficient about the center of gravity for these conditions is about 0.25. The ACES II ejection seat dimensions including a 50 percentile crewmember are

projected area	6.7 feet^2
hydraulic diameter	34.46 inches

determined as follows:

$$
\begin{aligned}
M_m &= (1/2\,\rho V^2)\ (S)\ (\ell)\ (C_m) \\
&= (2000\ \text{LBS/FT}^2)\ (6.7\ \text{FT}^2)\ (34.46\ \text{IN})\ (0.25) \\
&= 1.2 \times 10^5\ \text{IN-LBS} \\
&= 1.0 \times 10^4\ \text{FT-LBS}
\end{aligned}
$$

REACTION JET CONTROL

The reaction jet control system produces control moments by means of a series of nozzles mounted on a wedge 34 inches in

front of the seat. Thus the maximum required force from these nozzles is:

$$\text{FORCE} = \text{MOMENT/DISTANCE} = 1.2 \times 10^5 \text{ IN-LBS/34 IN}$$
$$= 3500 \text{ LBS}$$

The reaction jet force will be supplied by compressed nitrogen stored at 3000 psi, which is then throttled down to 150 psi. After this throttling, the nitrogen is preheated by the sustainer rocket gases to a temperature of 800°R.

The specific impulse (I) for a jet is the ratio of the thrust (F) divided by the weight flow rate ($\dot{W}$). For a gas expanding across a supersonic nozzle the specific impulse is also given by

$$I = \frac{V}{g}$$

where V = exit velocity of expanded gas
g = acceleration of gravity

The exit velocity of the gas is determined as follows (from Reference 6):

$$\frac{P}{P_t} = \frac{14.7}{150} = .098$$

$$P_t = P\left(1 + \frac{\gamma-1}{2}M^2\right)^{\frac{\gamma}{\gamma-1}}$$

$$M^2 = \frac{2}{\gamma-1}\left(\left(\frac{P}{P_t}\right)^{\frac{1-\gamma}{\gamma}} - 1\right)$$

$$M = \frac{2}{.4}\left((.098)^{-.2857} - 1\right)$$

$$M = 2.17$$

$$T = \frac{T_t}{\left(1 + \frac{\gamma-1}{2}M^2\right)}$$

$$T = \frac{800°R}{1.942} = 411°R$$

$$V = M * \sqrt{\gamma * g * R * T}$$
$$= 2.17\sqrt{1.4 * 32.2 * 55.1 * 411}$$
$$= 2195 \text{ ft/sec}$$

The specific impulse for this system is:

$$I = V/g \approx 70 \text{ secs}$$

The weight flow rate is now given by

$$\dot{W} = F/I = F/70$$

Considering a seat which decelerates from a dynamic pressure of 2000 psf to 500 psf the total weight of stored gas is given by

$$W = \int_0^{\tau} \dot{w}dt = \int_0^{\tau} F/70 \; dt$$

where F is the force required to counteract the upsetting moments.

A computer program was written to integrate the deceleration and flow rate. From this program, required weight of stored N_2 was found to be 23 pounds.

The 23 pounds of nitrogen is compressed to 3000 psi. The following calculation determines its volume at this pressure:

$$\bar{V} = \frac{mRT}{P},$$

$$\bar{V} = \frac{mRT}{P}, \text{ where } R_{N_2} = 55.1 \frac{ft\text{-}lb_f}{lb_m {}^\circ R}$$

$$P = 3000 \text{ psi} = 4.32 \times 10^5 \; lb_f/ft^2$$

$$T = 520^\circ R$$

$$\therefore \bar{V} = \frac{(23 \; lb_m)(55.1 \; ft\text{-}lb_f/lb_m {}^\circ R)(520^\circ R)}{(4.32 \times 10^5 \; lb_f/ft^2)}$$

$$= 1.53 \; ft^3$$

It is feasible to store this volume below or behind the seat.

APPENDIX D

TABLE D-1. SUMMARY OF WEIGHT ESTIMATIONS

	SEPARABLE FOREBODY	RETAINED WINDSHIELD	CURVED RAILS	CANOPY CAPSULE	OPTIONAL EJECTION DIRECTION
Weight	3448	3491	3454	3423	3506
Change	+25	+68	+31	0	+83
Weight Ratio	$\frac{3423}{3448}$	$\frac{3423}{3491}$	$\frac{3423}{3454}$	$\frac{3423}{3423}$	$\frac{3423}{3506}$
Weight Utility	.99	.98	.99	1.0	.98

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MODEL 987 - 230 B

MIL-STD-1374 COMPONENT BREAKDOWN

	WEIGHT					
	BASE	RETAINED WINDSCREEN	CANOPY CAPSULE	CURVED RAILS	OPTIONAL EJECTION DIRECTION	SEPARABLE FOREBODY
	(LB)	(LB)	(LB)	(LB)	(LB)	(LB)
STRUCTURE - PRIMARY						
NOSE - B.S. 45 TO 160	260	260	260	260	275	260
BULKHEAD - B.S. 155 (G/E)	16	16	16	16	16	16
- B.S. 224 (G/E)	18	18	18	18	18	18
- B.S. 304 / B.S. 320 (G/E)	24	24	24	24	24	24
MINOR FRAMES - B.S. 160-AFT (G/E)	32	32	32	32	32	14 40
JOINTS, SPLICES & FASTENERS	20	20	20	20	23	22
COVERING (SKINS - G/E)	52	52	52	52	64	84
STIFFENERS - COVERING	4	4	4	4	5	6
LONGERONS - SILL	80	80	80	80	85	80
- LOWER (G/E)	24	24	24	24	36	36
LONGITUDINAL PARTITIONS - (STRUCTURAL - G/E)	50	50	50	50	30	54
FLOORING & SUPPORTS - (BASIC STRUCTURE)	45	45	45	45	45	61
INSTALLATION PARTS	4	4	4	4	4	5
SEPARATION COMPONENTS - SEPARABLE FOREBODY	—	—	—	—	—	30
SHAPE CHARGE TO CUT LWR. BODY STRUCT. FOR DOWNWARD EJECT	—	—	—	—	5	—
STRUCTURE - SECONDARY						
CANOPY - TRANSPARENCY	100	100	100	105	100	100
- SUPPORT STRUCT.	105	105	110	110	105	105
- SHAPE CHARGE TO CUT CANOPY	—	2	—	—	—	—
CANOPY - OPERATING MECHANISM	55	55	56	55	55	55
- CYLINDERS, PLUMBING, FLUID	17	17	17	17	17	17
- EMERGENCY OPERATING SYS.	19	40	35	19	19	19
- FLUID	2	2	0	2	2	2
WINDSHIELD - TRANSPARENCY	71	71	71	71	71	71
- SUPPORT STRUCT.	18	18	22	18	18	18
FLOORING & SUPPORTS	3	3	3	3	3	5
ACCESS DOORS (TOTAL DOOR AREA - 35 FT²)	80	80	80	80	40	88
COCKPIT ACCESS STEPS &/OR GRIPS	14	14	14	14	14	14
EXTERIOR FINISH - PAINT & SEALANT	8	8	8	8	8	9
WINDSHIELD - EMERGENCY ACTUATION	20	20	—	20	20	20

(1)

	WEIGHT						
	BASE	RETAINED WINDSCREEN	CANOPY CAPSULE	CURVED RAILS	OPTIONAL EJECTION DIRECTION	SEPARABLE FOREBODY	
	(LB)	(LB)	(LB)	(LB)	(LB)	(LB)	(LB)
LANDING GEAR GP. – DROGUE CHUTE							
DECELERATION CHUTE & RELEASE MECH. ETC.						40	
ENGINE CONTROLS	20	20	20	20	20	20	
FLIGHT CONTROLS – COCKPIT CONTROLS	80	80	80	80	80	80	
– AUTOPILOT	90	90	90	90	90	90	
INSTRUMENTS	260	260	260	260	260	260	
ELECTRICAL	100	100	100	100	90	140	
AVIONICS	560	560	560	560	*245	**475	
FURNISHINGS							
EJECTION SEAT (2) (WEIGHTS ARE ADJUSTED FROM A SEAT WEIGHT OF 96 LBS/SEAT (NO F/B)) A. BASIC F-B	200	221	175	185	Ⓡ 291	151	
MOLDED FIBERGLAS SEATS (2)	SAME	—	—	—	—	—	
MOLDED PLASTIC SEATS (2)	—	(-15)	(-20)	(-20)	(-20)	(-20)	
HARNESS RELEASE MECHANISM (2)	SAME	SAME	SAME	SAME	SAME	SAME	
POWERED INERTIA REEL HAULBACK (2)	SAME	SAME	SAME	SAME	SAME	SAME	
LIMB RESTRAINT NET (2)	—	(+10)	(+10)	(+10)	(+10)	—	
RESTRAINT HARNESS (2)	SAME	SAME	SAME	SAME	SAME	SAME	
CATAPULT (2)	SAME	SAME	SAME	SAME	SAME	SAME	
ACTUATOR – SEAT PAN ROTATION – FWD SEAT	—	(+11)	—	—	—	—	

** 60 LBS AVIONICS MOVED OUT OF FOREBODY TO MAKE ROOM FOR R.A.T.
* 315 LBS AVIONICS MOVED TO LOCATION OUTSIDE THE FOREBODY AND DISPLACES 12.6 FT³ OF FUEL OR 610 LBS OF FUEL.

2

	WEIGHT						
	BASE	RETAINED WINDSCREEN	CANOPY CAPSULE	CURVED RAILS	OPTIONAL EJECTION DIRECTION	SEPARABLE FOREBODY	
	(LB)	(LB)	(LB)	(LB)	(LB)	(LB)	(LB)
FURNISHINGS - CON'T.							
EJECTION SEAT - CON'T.							
EMERGENCY OXYGEN UNIT (2)	SAME	SAME	SAME	SAME	SAME	NONE (-9)	
2000 LB-SEC. ROCKETS (2)/SEAT (2)	(+8)	—	—	—	(+8)	(+8)	
3000 LB-SEC. ROCKETS (2)/SEAT (2)	—	(+10)	—	—	—	—	
3000 LB-SEC. THRUST VECTORING ROCKET (2)/SEAT (2)	—	—	(+18)	—	—	—	
4000 LB-SEC. THRUST VECTORING ROCKET 2/SEAT (2)	—	—	—	(+28)	—	—	
SIDE ARM INITIATION HANDLES	SAME	SAME	SAME	SAME	SAME	SAME	
HEIGHT ADJUSTMENT ACTUATOR / SEAT (2)	SAME	SAME	SAME	SAME	SAME	SAME	
URT-33 LOCATOR BEACON / SEAT (2)	SAME	SAME	SAME	SAME	SAME	SAME	
GROUND SAFETY DISABLE UNIT / SEAT (2)	SAME	SAME	SAME	SAME	SAME	SAME	
DROGUE CHUTE / SEAT (2)	SAME	(-10)	SAME	SAME	SAME	SAME	
DROGUE CHUTE CONTAINER / SEAT (2)	SAME	(-4)	SAME	SAME	SAME	SAME	
DROGUE MORTAR GUN / SEAT (2)	SAME	(-12)	(-12)	(-12)	(-12)	(-12)	
DART / SEAT (2)	SAME	(-5)	(-5)	(-5)	(-5)	SAME	
BALLISTIC GAS SEQUENCING / ACTIVATION SYS. (2)	SAME	—	—	—	—	—	
MICROPROCESSOR SEQUENCING & CONTROL SYS. (2)	—	(-8)	(-8)	(-8)	(-8)	(-8)	
INFLATABLE AFTERBODY (INFLATABLE TUBES 10#, GAS GENERATORS [illegible], STOWAGE CONT. [illegible])	—	(+52)	—	—	—	—	
FLUIDIC GYRO & FLOW CONTROL UNITS / SEAT (2)	—	—	—	—	(+28)	—	
EXTENSION/SUPPORT TUBES / SEAT (2)	—	—	—	—	(+11)	—	
FLOW DEFLECTING WEDGE / SEAT (2)	—	—	—	—	(+3)	—	
Ⓡ GAS BOTTLE VOLUME = .75 FT^3/EA.					Ⓡ (40)		
Ⓡ NITROGEN (GAS) - 3000 PSI					Ⓡ (44)		
TRACKS & SUPPORTS	50	74	51	86	49	48	
ANTI-G SUIT PROVISIONS	8	8	8	8	8	8	
OXYGEN SYSTEM - REGULATOR	7	7	7	7	7	7	
- SUPPORTS - O_2 BOTTLE & REG.	8	8	8	8	8	8	
- OXYGEN SYS. PLUMBING	18	18	18	18	18	18	
- ELECT.	0	0	0	0	0	0	

(3)

	WEIGHT						
	BASE	RETAINED WINDSCREEN	CANOPY CAPSULE	CURVED RAILS	OPTIONAL EJECTION DIRECTION	SEPARABLE FOREBODY	
	(LB)	(LB)	(LB)	(LB)	(LB)	(LB)	(LB)
FURNISHINGS — CON'T.							
DATA CASE & FORM HOLDER	8	8	8	8	8	8	
WINDSHIELD RAIN REMOVAL	14	14	14	14	14	14	
REAR VIEW MIRROR	2	2	2	2	2	2	
INSTRUMENT BOARDS & CONSOLES — FWD CENTER	13	13	13	13	13	13	
— FWD RIGHT	9	9	9	9	9	9	
— FWD LEFT	11	11	11	11	11	11	
— AFT RIGHT	12	12	12	12	12	12	
— AFT LEFT	12	12	12	12	12	12	
INSTRUMENT PANEL — EMERGENCY RETRACTION ACTUATION	—	—	20	—	—	—	
GLARE SHIELD (2)	8	8	8	8	8	8	
COCKPIT INSULATION (1.5 IN. THICK)	10	10	10	10	10	10	
TRIM & KICK PLATES	6	6	6	6	6	6	
FIRE EXTINGUISHING SYSTEM — BOTTLE	16	16	16	16	16	16	
— PLUMBING	4	4	4	4	4	4	
— SUPPORTS	1	1	1	1	1	1	
DETECTION SYSTEMS — FIRE	10	10	10	10	10	10	
— BLEED AIR LEAK	3	3	3	3	3	3	
— INLET ICE	2	2	2	.2	2	2	
— WIRING	10	10	10	10	10	10	

4.

	WEIGHT						
	BASE	RETAINED WINDSCREEN	CANOPY CAPSULE	CURVED RAILS	OPTIONAL EJECTION DIRECTION	SEPARABLE FOREBODY	
	(LB)	(LB)	(LB)	(LB)	(LB)	(LB)	(LB)
AIRCONDITIONING – DISTRUBUTION – CABIN [illegible]	40	40	40	40	40	40	
– AVIONICS	40	40	40	40	40	40	
USEFUL LOAD –							
CREW – (2)	430	430	430	430	430	430	
– "G" SUIT (2)	—	—	—	—	—	5	
(2) PRESSURE SUIT, HELMET, BOOTS, & GLOVES (INCL. "G" SUIT)	56	56	56	56	56	—	
– OXYGEN – CONVERTER	15	15	15	15	15	15	
– LIQUID OXYGEN	25	25	25	25	25	25	
– PARACHUTE	48	48	48	48	48	48	
– SURVIVAL KIT	76	76	76	76	76	76	
TOTAL FOREBODY WEIGHT (ALL COMPAREABLE WITH SEPARABLE FOREBODY CONCEPT)	3,423	3,491	3,423	3,454	* 3,191 (R)	3,448	

* 315 LBS. AVIONICS MOVED TO LOCATION OUTSIDE THE FOREBODY AND DISPLACES 12.6 FT^3 OF FUEL OR 610 LBS OF FUEL

(5.)

APPENDIX E

TABLE E-1. SUMMARY OF VOLUME ESTIMATIONS

	SEPARABLE FOREBODY	RETAINED WINDSHIELD	CURVED RAILS	CANOPY CAPSULE	OPTIONAL EJECTION DIRECTION
Measured Area by Planimeter	1.26	1.12	1.09	1.25	1.13
Converted Area* (ft^2)	35	31	30	35	31
Volume Ratio	$\frac{30}{35}$	$\frac{30}{31}$	$\frac{30}{30}$	$\frac{30}{35}$	$\frac{30}{31}$
Volume Penalty	.8	1.0	1.0	.8	1.0

* Conversion Factor: 1 planimeter unit = 27.9 ft^2

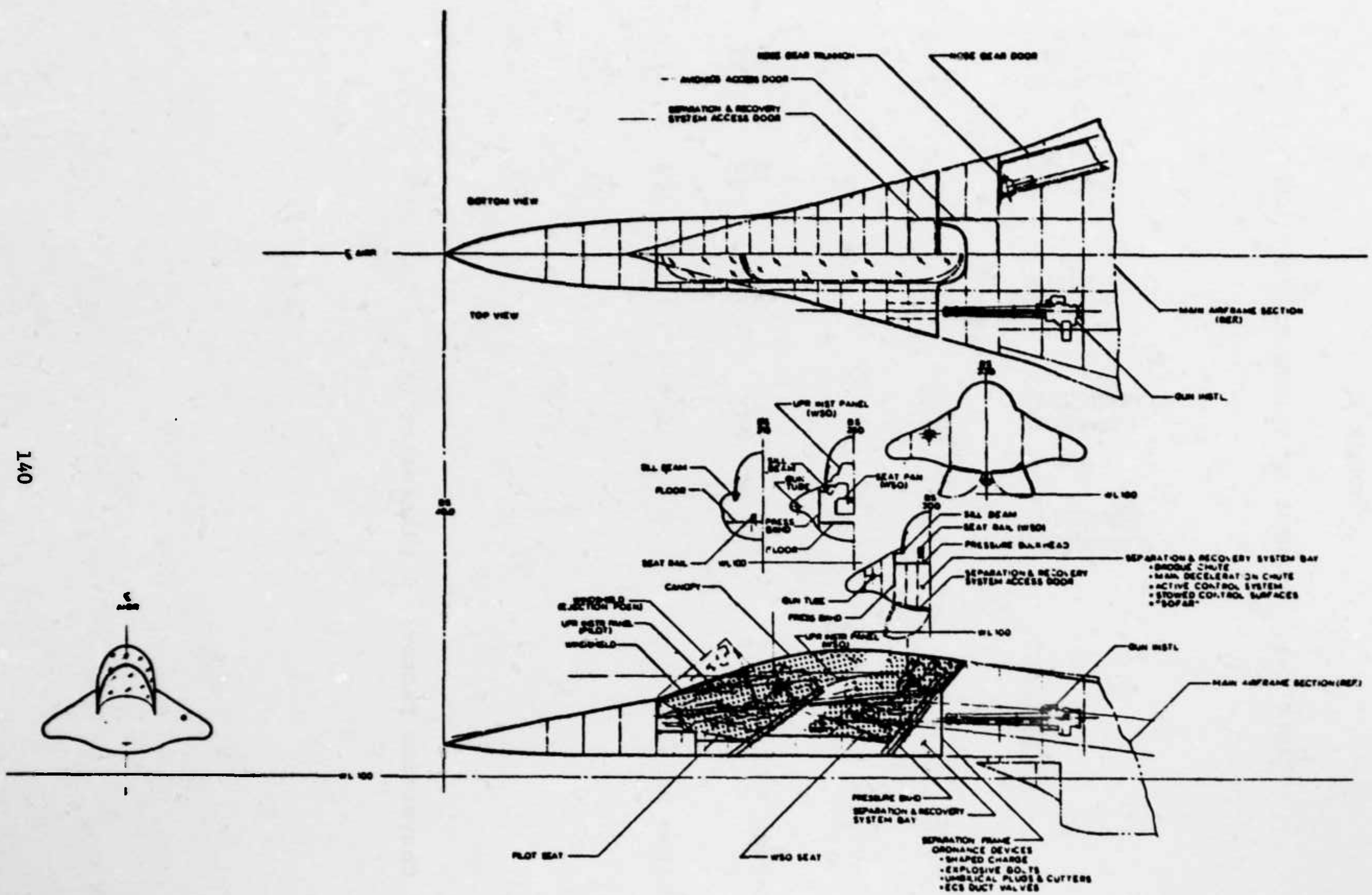

FIGURE E-1 SEPARABLE FOREBODY CONFIGURATION

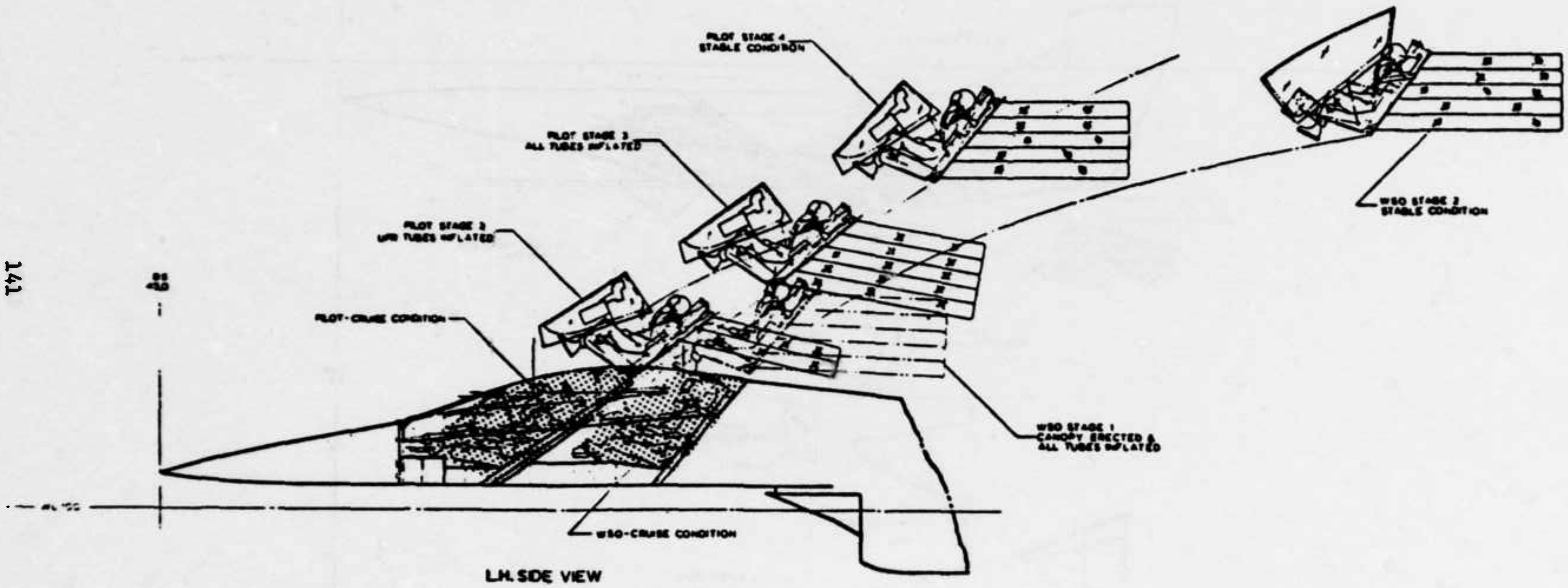

FIGURE E-2 RETAINED WINDSCREEN - STREAMLINED AFTERBODY CONFIGURATION

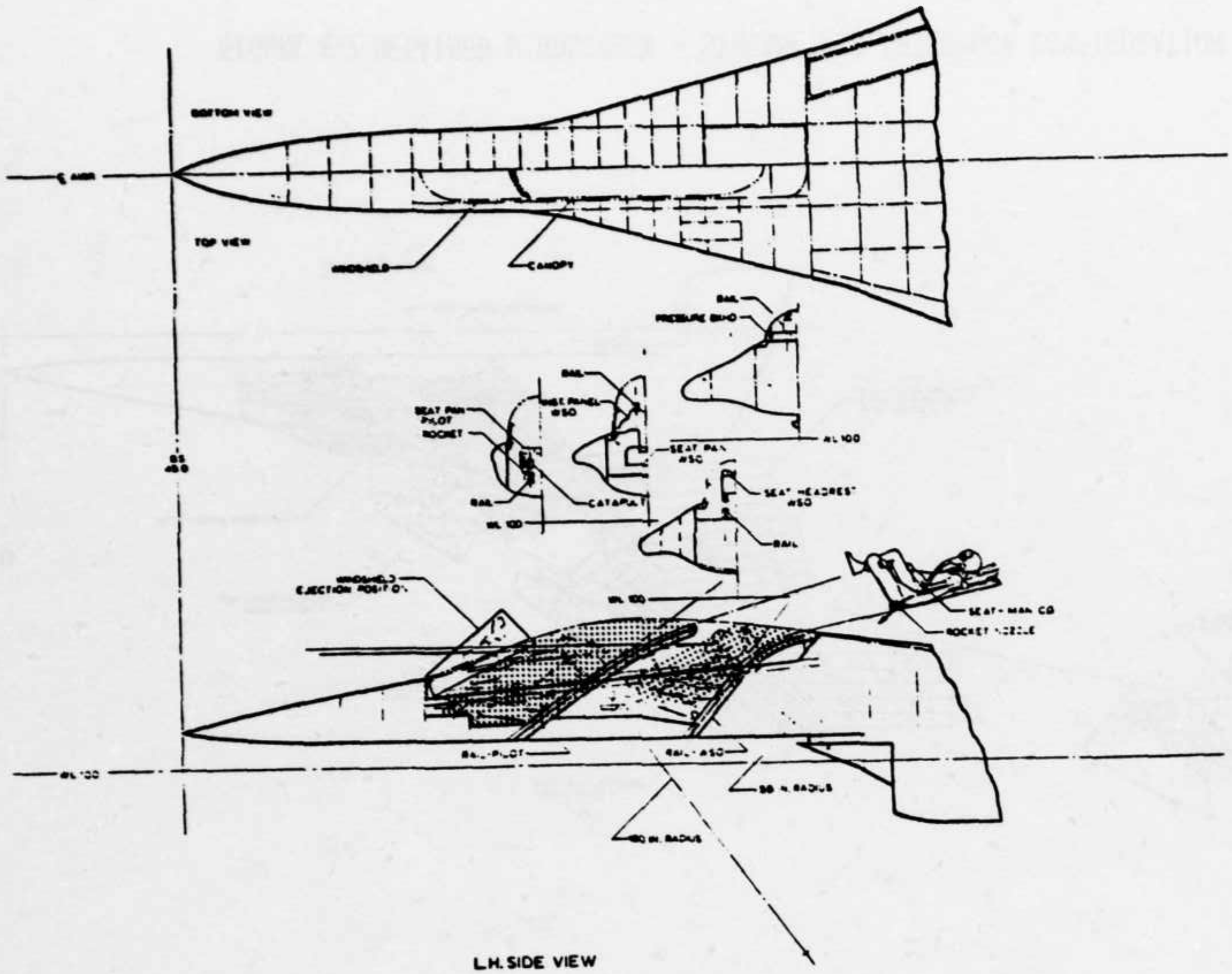

FIGURE E-3 CURVED RAILS - VECTORED THRUST CONFIGURATION

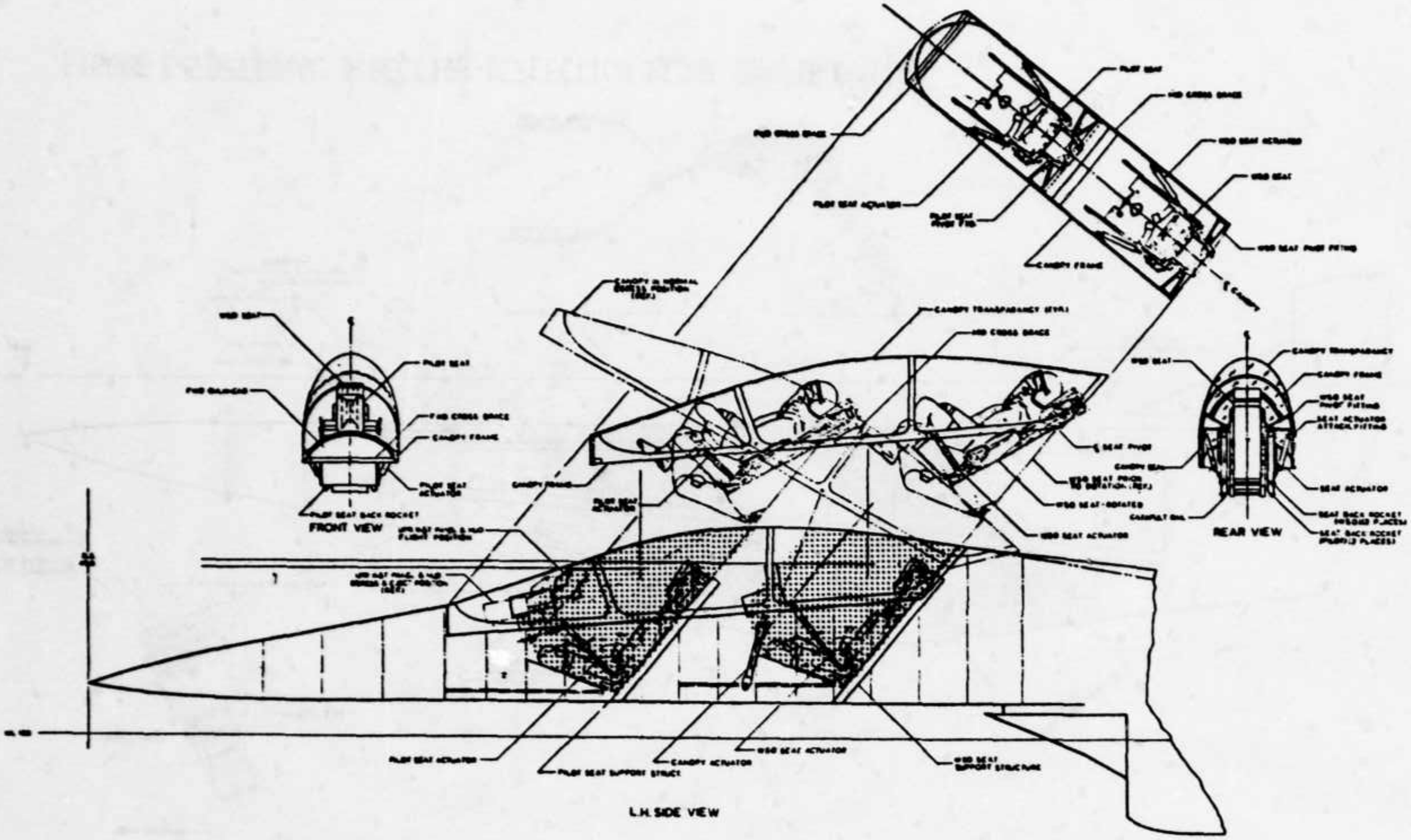

FIGURE E-4 CANOPY CAPSULE - VECTORED THRUST CONFIGURATION

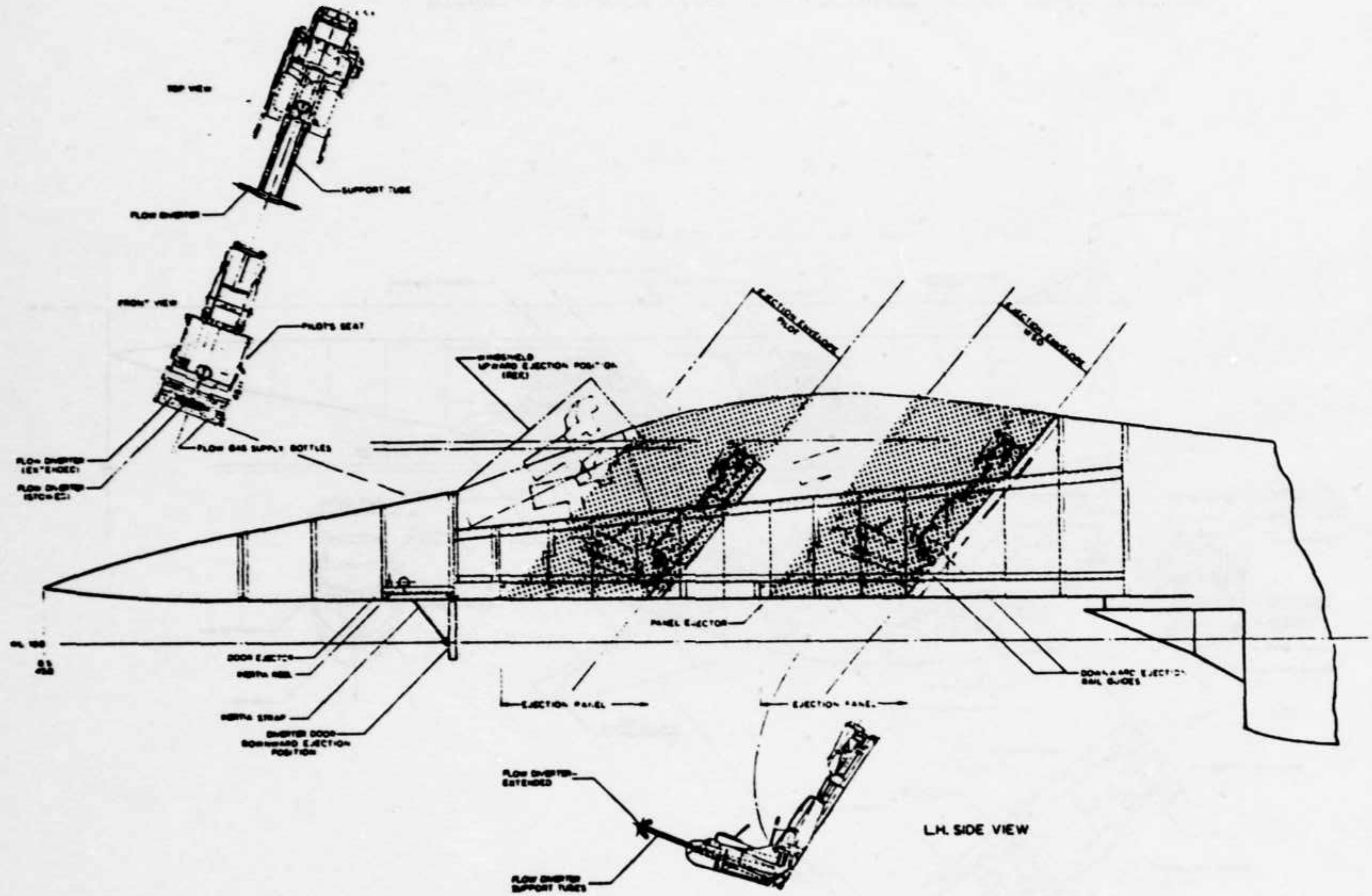

FIGURE E-5 OPTIONAL DIRECTION-DEFLECTION WEDGE CONFIGURATION

APPENDIX F

TABLE F-1. INTERFACE REQUIREMENTS SUMMARY

	SEPARABLE FOREBODY	RETAINED WINDSHIELD	CURVED RAILS	CANOPY CAPSULE	OPTIONAL EJECTION DIRECTION
Number of Interfaces	26	32	17	20	23
Interface Ratio	17/26	17/32	17/17	17/20	17/23
Interface Utility	.65	.53	1	.85	.74

APPENDIX F

EVALUATION OF AIRCRAFT/ESCAPE SYSTEM INTERFACES

	Retained Windshield Qty	Canopy Capsule Qty	Curved Rails Qty	Optional Ejection Direction Qty	Separable Forebody Qty
Molded Plastic Seat	2	2	2	2	2
Restraint Harness	2	2	2	2	2
Powered Inertia Reel	2	2	2	2	2
Harness Release Unit	2	2	2	2	2
Limb Restraint Net	4	4	4	4	-
Optional Catapult Firing Unit	-	-	-	4	-
Catapult	4	4	4	4	4
Catapult Pivot	-	-	4	-	-
Guide Rails	4 I	-	-	4 I	4 I
Guide Rail Extensions	4 I	-	-	4 I	-
Curved Guide Rails	-	-	4 I	-	-
Guide Rail Supports	-	-	4 I	-	-
Sustainer Rockets	4	4	4	4	4
TVC Nozzle	-	4	4	-	-
Windshield Erection Actuator	1 I	-	1 I	1 I	1 I
Seat Adjustment Actuator	2 I	2 I	2 I	2 I	2 I
Seat Rotation Actuator	-	2 I	-	-	-
Display Panel Retraction Actuator	-	1 I	-	-	-
Canopy Thruster	1 I	2 I	2 I	2 I	2 I
Windshield Repositioning Actuator	2 I	-	-	-	-
Auxiliary Equipment Disconnects	2 I	2 I	2 I	2 I	2 I

	Retained Windshield Qty	Canopy Capsule Qty	Curved Rails Qty	Optional Ejection Direction Qty	Separable Forebody Qty
Sidearm Initiation Handles	4	4	4	4	4
URT 33 Locator Pact	2	2	2	2	2
Emergency O_2 Unit	2	2	2	2	2
Survival Kit	2	2	2	2	2
Ground Safety Disable Unit	2 I	2 I	2 I	2 I	2 I
Pressure Suit/G Suit	2	2	2	2	-
Drogue Chute	-	2	2	2	2
Drogue Chute Container	-	2	2	2	2
Drogue Mortar Gun	-	-	2	-	2
Personnel Chute	2	2	2	2	2
Microprocessor Sequencing & Control	2	1	2	2	2
Fluidic Rate Sensor & Control	-	-	-	2	-
High Pressure Stored Gas	-	-	-	4	-
Flow Diverter Support Tubes	-	-	-	4	-
Flow Diverter Manifold & Nozzles	-	-	-	2	-
Inflatable Afterbody Tubes	2	-	-	-	-
Afterbody Support Frame	2	-	-	-	-
Afterbody Supply Bottles	4	-	-	-	-
Aftbody Supply Tubes & Valves	2	-	-	-	-
Canopy/Seat Pivot Pins	-	4 I	-	-	-

	Retained Windshield Qty	Canopy Capsule Qty	Curved Rails Qty	Optional Ejection Direction Qty	Separable Forebody Qty
Explosive Bolts	4 I	4 I	-	-	-
Windshield Support Struts	4 I	-	-	-	-
Canopy Seat Separation Actuators	4 I	-	-	-	-
Canopy Severance Shape Changes	2 I	1 I	-	-	-
Roller Guide Rail Truck Key	-	-	8	-	-
Panel Severance Charges	-	-	-	2 I	-
Panel Thrusters	-	-	-	2 I	-
Protection Shield	-	-	-	1 I	-
Protection Shield Actuator	-	-	-	1 I	-
Forebody Severance Shape Change	-	-	-	-	1 I
ECS Disconnection Unit	-	-	-	-	1 I
Electrical Severance Unit	-	-	-	-	1 I
Hydraulic Severance Unit	-	-	-	-	1 I
Mechanical Severance Unit	-	-	-	-	1 I
Ram Air Turbine	-	-	-	-	1 I
Ram Air Inlet Doors/ Scoops	-	-	-	-	2 I
RAT Electrical Connection	-	-	-	-	1 I
RAT Door Actuator	-	-	-	-	2 I
DART	-	-	-	-	2 I

APPENDIX G

TABLE G-1. SUMMARY OF LIFE CYCLE COST

	SEPARABLE FOREBODY	RETAINED WINDSHIELD	CURVED RAILS	CANOPY CAPSULE	OPTIONAL EJECTION DIRECTION
Total Life Cycle Cost ($\times 10^{6}$ Dollars)	73.751	64.259	58.482	71.716	74.101
Cost Ratio	$\frac{58.482}{73.751}$	$\frac{58.482}{64.259}$	$\frac{58.482}{58.482}$	$\frac{58.482}{71.716}$	$\frac{58.482}{74.101}$
Cost Utility	.79	.91	1	.82	.79

APPENDIX G

CREW ESCAPE SYSTEM LIFE CYCLE COSTS

FY 1977 DOLLARS IN MILLIONS

COST ELEMENT	CREW ESCAPE SYSTEM CONCEPT				
	SEPARABLE FOREBODY(1)	RETAINED WIND SCREEN	CANOPY CAPSULE(2)	OPTIONAL DIRECTION	CURVED RAILS
DEVELOPMENT COST (20 Flt Test Units)	$20.557	$10.672	$18.325	$13.104	$ 9.598
ACQUISITION COST (500 Units)	30.007	30.007	30.007	36.372	27.269
OPERATIONS & SUPPORT COST (15 Years)	23.187	23.580	23.384	24.625	21.615
TOTAL LIFE CYCLE COST	$73.751	$64.259	$71.716	$74.101	$58.482

(1) ACQUISITION COSTS DO NOT INCLUDE FOREBODY STRUCTURE.

(2) ACQUISITION COSTS DO NOT INCLUDE STRUCTURAL COMPONENTS.

APPENDIX H

TABLE H-1. SUMMARY OF COMPONENT DEVELOPMENT STATUS

	SEPARABLE FOREBODY	RETAINED WINDSHIELD	CURVED RAILS	CANOPY CAPSULE	OPTIONAL EJECTION DIRECTION
Number of					
a) currently available	18	14	16	15	15
b) modified	10	10	5	9	10
c) new	4	6	6	2	7
Total components	32	30	28	26	32
Development status ratio	$\frac{23}{32}$	$\frac{19}{30}$	$\frac{19}{28}$	$\frac{20}{26}$	$\frac{20}{32}$
Development status utility	.72	.63	.68	.77	.63

APPENDIX H

EVALUATION OF COMPONENT DEVELOPMENT STATUS

	Retained Windshield Qty	Canopy Capsule Qty	Curved Rails Qty	Optional Ejection Direction Qty	Separable Forebody Qty
Molded Plastic Seat	2 MOD	2 MOD	2 MOD	2 MOD	2 MOD
Restraint Harness	2 MOD	2 MOD	2 NEW	2 MOD	2 MOD
Powered Inertia Reel	2 CUR	2 CUR	2 CUR	2 CUR	2 CUR
Harness Release Unit	2 CUR	2 CUR	2 CUR	2 CUR	2 CUR
Limb Restraint Net	4 NEW	4 NEW	4 NEW	4 NEW	-
Optional Catapult Firing Unit	-	-	-	4 NEW	-
Catapult	4 CUR	4 CUR	4 CUR	4 NEW	4 CUR
Catapult Pivot	-	-	4 NEW	-	-
Guide Rails	4 MOD	-	-	4 MOD	4 CUR
Guide Rail Extensions	4 MOD	-	-	4 NEW	-
Curved Guide Rails	-	-	4 NEW	-	-
Guide Rail Supports	-	-	4 MOD	-	-
Sustainer Rockets	4 CUR	4 CUR	4 CUR	4 CUR	4 CUR
TVC Nozzle	-	4 NEW	4 NEW	-	-
Windshield Erection Actuator	1 MOD	-	1 MOD	1 MOD	1 MOD
Seat Adjustment Actuator	2 MOD	2 MOD	2 MOD	2 MOD	2 MOD
Seat Rotation Actuator	-	2 MOD	-	-	-
Display Panel Retraction Actuator	-	1 MOD	-	-	-
Canopy Thruster	1 CUR	2 CUR	2 CUR	2 CUR	2 CUR
Windshield Repositioning Actuator	2 MOD	-	-	-	-
Auxiliary Equipment Disconnects	2 CUR	2 CUR	2 CUR	2 CUR	2 CUR

	Retained Windshield Qty	Canopy Capsule Qty	Curved Rails Qty	Optional Ejection Direction Qty	Separable Forebody Qty
Sidearm Initiation Handles	4 CUR	4 CUR	4 CUR	4 CUR	4 CUR
URT 33 Locator Pact	2 CUR	2 CUR	2 CUR	2 CUR	2 CUR
Emergency O_2 Unit	2 CUR	2 CUR	2 CUR	2 CUR	2 CUR
Survival Kit	2 CUR	2 CUR	2 CUR	2 CUR	2 CUR
Ground Safety Disable Unit	2 CUR	2 MOD	2 CUR	2 CUR	2 CUR
Pressure Suit/G Suit	2 CUR	2 CUR	2 CUR	2 CUR	- CUR
Drogue Chute	-	2 CUR	2 CUR	2 CUR	2 CUR
Drogue Chute Container	-	2 CUR	2 CUR	2 CUR	2 CUR
Drogue Mortar Gun	-	-	2 CUR	-	2 CUR
Personnel Chute	2 CUR	2 CUR	2 CUR	2 CUR	2 CUR
Microprocessor Sequencing & Control	2 MOD	1 MOD	2 MOD	2 MOD	2 MOD
Fluidic Rate Sensor & Control	-	-	-	2 MOD	-
High Pressure Stored Gas	-	-	-	4 CUR	-
Flow Diverter Support Tubes	-	-	-	4 NEW	-
Flow Diverter Manifold & Nozzles	-	-	-	2 NEW	-
Inflatable Afterbody Tubes	2 NEW	-	-	-	-
Afterbody Support Frame	2 NEW	-	-	-	-
Afterbody Supply Bottles	4 NEW	-	-	-	-
Aftbody Supply Tubes & Valves	2 NEW	-	-	-	-
Canopy/Seat Pivot Pins	-	4 MOD	-	-	-

	Retained Windshield Qty	Canopy Capsule Qty	Curved Rails Qty	Optional Ejection Direction Qty	Separable Forebody Qty
Explosive Bolts	4 CUR	4 CUR	-	-	-
Windshield Support Struts	4 NEW	-	-	-	-
Canopy Seat Separation Actuators	4 MOD	-	-	-	-
Canopy Severance Shape Changes	2 MOD	1 MOD	-	-	-
Roller Guide Rail Truck Key	-	-	8 NEW	-	-
Panel Severance Charges	-	-	-	2 MOD	-
Panel Thrusters	-	-	-	2 MOD	-
Protection Shield	-	-	-	1 NEW	-
Protection Shield Actuator	-	-	-	1 MOD	-
Forebody Severance Shape Change	-	-	-	-	1 MOD
ECS Disconnection Unit	-	-	-	-	1 MOD
Electrical Severance Unit	-	-	-	-	1 MOD
Hydraulic Severance Unit	-	-	-	-	1 MOD
Mechanical Severance Unit	-	-	-	-	1 MOD
Ram Air Turbine	-	-	-	-	1 NEW
Ram Air Inlet Doors/ Scoops	-	-	-	-	2 NEW
RAT Electrical Connection	-	-	-	-	1 NEW
RAT Door Actuator	-	-	-	-	2 NEW
DART	-	-	-	-	2 CUR

APPENDIX I

TABLE I-1. SUMMARY OF CONCEPT COMPONENTS

	SEPARABLE FOREBODY	RETAINED WINDSHIELD	CURVED RAILS	CANOPY CAPSULE	OPTIONAL EJECTION DIRECTION
Number of Components	62	78	75	63	79
Reliability Ratio	$\frac{62}{62}$	$\frac{62}{78}$	$\frac{62}{75}$	$\frac{62}{63}$	$\frac{62}{78}$
Reliability Utility	1.0	.79	.83	.98	.79

APPENDIX I

SUBSYSTEM AND COMPONENT EQUIPMENT LIST

	Retained Windshield Qty	Canopy Capsule Qty	Curved Rails Qty	Optional Ejection Direction Qty	Separable Forebody Qty
Molded Plastic Seat	2	2	2	2	2
Restraint Harness	2	2	2	2	2
Powered Inertia Reel	2	2	2	2	2
Harness Release Unit	2	2	2	2	2
Limb Restraint Net	4	4	4	4	-
Optional Catapult Firing Unit	-	-	-	4	-
Catapult	4	4	4	4	4
Catapult Pivot	-	-	4	-	-
Guide Rails	4	-	-	4	4
Guide Rail Extensions	4	-	-	4	-
Curved Guide Rails	-	-	4	-	-
Guide Rail Supports	-	-	4	-	-
Sustainer Rockets	4	4	4	4	4
TVC Nozzle	-	4	4	-	-
Windshield Erection Actuator	1	-	1	1	1
Seat Adjustment Actuator	2	2	2	2	2
Seat Rotation Actuator	-	2	-	-	-
Display Panel Retraction Actuator	-	1	-	-	-
Canopy Thruster	1	2	2	2	2
Windshield Repositioning Actuator	2	-	-	-	-
Auxiliary Equipment Disconnects	2	2	2	2	2

	Retained Windshield Qty	Canopy Capsule Qty	Curved Rails Qty	Optional Ejection Direction Qty	Separable Forebody Qty
Sidearm Initiation Handles	4	4	4	4	4
URT 33 Locator Pact	2	2	2	2	2
Emergency O_2 Unit	2	2	2	2	2
Survival Kit	2	2	2	2	2
Ground Safety Disable Unit	2	2	2	2	2
Pressure Suit/G Suit	2	2	2	2	-
Drogue Chute	-	2	2	2	2
Drogue Chute Container	-	2	2	2	2
Drogue Mortar Gun	-	-	2	-	2
Personnel Chute	2	2	2	2	2
Microprocessor Sequencing & Control	2	1	2	2	2
Fluidic Rate Sensor & Control	-	-	-	2	-
High Pressure Stored Gas	-	-	-	4	-
Flow Diverter Support Tubes	-	-	-	4	-
Flow Diverter Manifold & Nozzles	-	-	-	2	-
Inflatable Afterbody Tubes	2	-	-	-	-
Afterbody Support Frame	2	-	-	-	-
Afterbody Supply Bottles	4	-	-	-	-
Aftbody Supply Tubes & Valves	2	-	-	-	-
Canopy/Seat Pivot Pins	-	4	-	-	-

	Retained Windshield Qty	Canopy Capsule Qty	Curved Rails Qty	Optional Ejection Direction Qty	Separable Forebody Qty
Explosive Bolts	4	4	-	-	-
Windshield Support Struts	4	-	-	-	-
Canopy Seat Separation Actuators	4	-	-	-	-
Canopy Severance Shape Changes	2	1	-	-	-
Roller Guide Rail Truck Key	-	-	8	-	-
Panel Severance Charges	-	-	-	2	-
Panel Thrusters	-	-	-	2	-
Protection Shield	-	-	-	1	-
Protection Shield Actuator	-	-	-	1	-
Forebody Severance Shape Change	-	-	-	-	1
ECS Disconnection Unit	-	-	-	-	1
Electrical Severance Unit	-	-	-	-	1
Hydraulic Severance Unit	-	-	-	-	1
Mechanical Severance Unit	-	-	-	-	1
Ram Air Turbine	-	-	-	-	1
Ram Air Inlet Doors/ Scoops	-	-	-	-	2
RAT Electrical Connection	-	-	-	-	1
RAT Door Actuator	-	-	-	-	2
DART	-	-	-	-	2

APPENDIX J

TABLE J-1. SUMMARY OF OPERATIONAL LIFE

	SEPARABLE FOREBODY	RETAINED WINDSHIELD	CURVED RAILS	CANOPY CAPSULE	OPTIONAL EJECTION DIRECTION
Average Operational Life	14.8	15.3	16.8	15.1	16.5
Operational Life Ratio	$\frac{14.8}{20}$	$\frac{15.3}{20}$	$\frac{16.8}{20}$	$\frac{15.1}{20}$	$\frac{16.5}{20}$
Operational Life Utility	.74	.77	.84	.76	.83

APPENDIX J

EVALUATION OF COMPONENT OPERATIONAL LIFE

	Retained Windshield Qty		Canopy Capsule Qty		Curved Rails Qty		Optional Ejection Direction Qty		Separable Forebody Qty	
Molded Plastic Seat	2	20	2	20	2	20	2	20	2	20
Restraint Harness	2	20	2	20	2	20	2	20	2	20
Powered Inertia Reel	2	20	2	20	2	20	2	20	2	20
Harness Release Unit	2	6	2	6	2	6	2	6	2	6
Limb Restraint Net	4	20	4	20	4	20	4	20	-	
Optional Catapult Firing Unit	-		-		-		4	20	-	
Catapult	4	6	4	6	4	6	4	6	4	6
Catapult Pivot	-		-		4	20	-		-	
Guide Rails	4	20	-		-		4	20	4	20
Guide Rail Extensions	4	20	-		-		4	20	-	
Curved Guide Rails	-		-		4	20	-		-	
Guide Rail Supports	-		-		4	20	-		-	
Sustainer Rockets	4	6	4	6	4	6	4	6	4	6
TVC Nozzle	-		4	20	4	20	-		-	
Windshield Erection Actuator	1	6	-		1	6	1	6	1	6
Seat Adjustment Actuator	2	6	2	6	2	6	2	6	2	6
Seat Rotation Actuator	-		2	6	-		-		-	
Display Panel Retraction Actuator	-		1	6	-		-		-	
Canopy Thruster	1	6	2	6	2	6	2	6	2	6
Windshield Repositioning Actuator	2	6	-		-		-		-	
Auxiliary Equipment Disconnects	2	20	2	20	2	20	2	20	2	20

	Retained Windshield Qty		Canopy Capsule Qty		Curved Rails Qty		Optional Ejection Direction Qty		Separable Forebody Qty	
Sidearm Initiation Handles	4	20	4	20	4	20	4	20	4	20
URT 33 Locator Pact	2	20	2	20	2	20	2	20	2	20
Emergency O_2 Unit	2	20	2	20	2	20	2	20	2	20
Survival Kit	2	20	2	20	2	20	2	20	2	20
Ground Safety Disable Unit	2	20	2	20	2	20	2	20	2	20
Pressure Suit/G Suit	2	20	2	20	2	20	2	20	-	
Drogue Chute	-		2	20	2	20	2	20	2	20
Drogue Chute Container	-		2	20	2	20	2	20	2	20
Drogue Mortar Gun	-		-		2	6	-		2	6
Personnel Chute	2	20	2	20	2	20	2	20	2	20
Microprocessor Sequencing & Control	2	20	1	20	2	20	2	20	2	20
Fluidic Rate Sensor & Control	-		-		-		2	20	-	
High Pressure Stored Gas	-		-		-		4	20	-	
Flow Diverter Support Tubes	-		-		-		4	20	-	
Flow Diverter Manifold & Nozzles	-		-		-		2	20	-	
Inflatable Afterbody Tubes	2	20	-		-		-		-	
Afterbody Support Frame	2	20	-		-		-		-	
Afterbody Supply Bottles	4	20	-		-		-		-	
Aftbody Supply Tubes & Valves	2	20	-		-		-		-	
Canopy/Seat Pivot Pins	-		4	20	-		-		-	

	Retained Windshield Qty		Canopy Capsule Qty		Curved Rails Qty		Optional Ejection Direction Qty		Separable Forebody Qty	
Explosive Bolts	4	6	4	6	-		-		-	
Windshield Support Struts	4	20	-		-		-		-	
Canopy Seat Separation Actuators	4	6	-		-		-		-	
Canopy Severance Shape Changes	2	6	1	6	-		-		-	
Roller Guide Rail Truck Key	-		-		8	20	-		-	
Panel Severance Charges	-		-		-		2	6	-	
Panel Thrusters	-		-		-		2	6	-	
Protection Shield	-		-		-		1	20	-	
Protection Shield Actuator	-		-		-		1	6	-	
Forebody Severance Shape Change	-		-		-		-		1	6
ECS Disconnection Unit	-		-		-		-		1	20
Electrical Severance Unit	-		-		-		-		1	6
Hydraulic Severance Unit	-		-		-		-		1	6
Mechanical Severance Unit	-		-		-		-		1	6
Ram Air Turbine	-		-		-		-		1	20
Ram Air Inlet Doors/ Scoops	-		-		-		-		2	20
RAT Electrical Connection	-		-		-		-		1	20
RAT Door Actuator	-		-		-		-		2	6
DART	-		-		-		-		2	20

APPENDIX K

TABLE K-1. SUMMARY OF COMPONENT ACCESSIBILITY

	SEPARABLE FOREBODY	RETAINED WINDSHIELD	CURVED RAILS	CANOPY CAPSULE	OPTIONAL EJECTION DIRECTION
Number of Accessible Components	47	37	56	45	58
Number of Components	62	78	75	63	79
Accessibility Ratio	$\frac{47}{62}$	$\frac{37}{78}$	$\frac{56}{75}$	$\frac{45}{63}$	$\frac{58}{79}$
Maintainability Utility	.76	.47	.75	.71	.73

APPENDIX K

EVALUATION OF COMPONENT ACCESSIBILITY

	Retained Windshield Qty		Canopy Capsule Qty		Curved Rails Qty		Optional Ejection Direction Qty		Separable Forebody Qty	
Molded Plastic Seat	2	A	2	A	2	A	2	A	2	A
Restraint Harness	2	A	2	A	2	A	2	A	2	A
Powered Inertia Reel	2		2		2		2		2	
Harness Release Unit	2		2		2		2		2	
Limb Restraint Net	4	A	4	A	4	A	4	A	-	A
Optional Catapult Firing Unit	-		-		-		4		-	
Catapult	4	A	4	A	4	A	4	A	4	A
Catapult Pivot	-		-		4		-		-	
Guide Rails	4	A	-		-		4	A	4	A
Guide Rail Extensions	4		-		-		4		-	
Curved Guide Rails	-		-		4	A	-		-	
Guide Rail Supports	-		-		4	A	-		-	
Sustainer Rockets	4	A	4	A	4	A	4	A	4	A
TVC Nozzle	-		4	A	4	A	-		-	
Windshield Erection Actuator	1		-		1		1		1	
Seat Adjustment Actuator	2	A	2	A	2	A	2	A	2	A
Seat Rotation Actuator	-		2		-		-		-	
Display Panel Retraction Actuator	-		1		-		-		-	
Canopy Thruster	1		2		2		2		2	
Windshield Repositioning Actuator	2	A	-		-		-		-	
Auxiliary Equipment Disconnects	2	A	2	A	2	A	2	A	2	A

	Retained Windshield Qty		Canopy Capsule Qty		Curved Rails Qty		Optional Ejection Direction Qty		Separable Forebody Qty	
Sidearm Initiation Handles	4	A	4	A	4	A	4	A	4	A
URT 33 Locator Pact	2	A	2	A	2	A	2	A	2	A
Emergency O_2 Unit	2	A	2	A	2	A	2	A	2	A
Survival Kit	2	A	2	A	2	A	2	A	2	A
Ground Safety Disable Unit	2	A	2	A	2	A	2	A	2	A
Pressure Suit/G Suit	2	A	2	A	2	A	2	A	-	
Drogue Chute	-		2	A	2	A	2	A	2	A
Drogue Chute Container	-		2	A	2	A	2	A	2	A
Drogue Mortar Gun	-		-		2	A	-		2	A
Personnel Chute	2	A	2	A	2	A	2	A	2	A
Microprocessor Sequencing & Control	2	A	1	A	2	A	2	A	2	A
Fluidic Rate Sensor & Control	-		-		-		2	A	-	
High Pressure Stored Gas	-		-		-		4	A	-	
Flow Diverter Support Tubes	-		-		-		4	A	-	
Flow Diverter Manifold & Nozzles	-		-		-		2	A	-	
Inflatable Afterbody Tubes	2	A	-		-		-		-	
Afterbody Support Frame	2	A	-		-		-		-	
Afterbody Supply Bottles	4	A	-		-		-		-	
Aftbody Supply Tubes & Valves	2	A	-		-		-		-	
Canopy/Seat Pivot Pins	-		4		-		-		-	

	Retained Windshield Qty	Canopy Capsule Qty	Curved Rails Qty	Optional Ejection Direction Qty	Separable Forebody Qty
Explosive Bolts	4	4	-	-	-
Windshield Support Struts	4 A	-	-	-	-
Canopy Seat Separation Actuators	4	-	-	-	-
Canopy Severance Shape Changes	2	1	-	-	-
Roller Guide Rail Truck Key	-	-	8	-	-
Panel Severance Charges	-	-	-	2	-
Panel Thrusters	-	-	-	2	-
Protection Shield	-	-	-	1	-
Protection Shield Actuator	-	-	-	1	-
Forebody Severance Shape Change	-	-	-	-	1
ECS Disconnection Unit	-	-	-	-	1
Electrical Severance Unit	-	-	-	-	1
Hydraulic Severance Unit	-	-	-	-	1
Mechanical Severance Unit	-	-	-	-	1
Ram Air Turbine	-	-	-	-	1
Ram Air Inlet Doors/ Scoops	-	-	-	-	2 A
RAT Electrical Connection	-	-	-	-	1 A
RAT Door Actuator	-	-	-	-	2
DART	-	-	-	-	2 A

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